Geometry, Form and Structure Relationship in Blob, Liquid and Formless Architecture

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ABSTRACT

Structure is a historical and complicated issue of architecture but today the progress in technology has helped architects to overcome the limitations and to reach their goals in design. Apart from structure the form is another matter that architects need to consider because it influences both the interior and exterior of any building. This study therefore, intends to analyze the form and structure in 3 dimensional of blob, liquid and formless architecture. This thesis aimed at integrating different types of constructions and techniques in order to analyze how it is possible to achieve formlessness by considering the issue of structure, in dome, shell, grid shell, pneumatic and membrane structures. In other words, the three dimensional and irregular blob, liquid and formless architecture has been discussed, in order to find out the structure and form organization and the relationship between them. It is shown that structures of three dimensional Blob, Liquid and Formless architecture all have wide span enclosure with small thickness. Also, the results of this research present a method that makes use of simple and complicated geometries and hyperbolic paraboloid.

Keyword: Structure, space, formless, blob architecture, liquid architecture

ÖZ

Taşıyıcı sistem konusu mımarlıkta tarıhsel ve karmaşık bır konu olmakla birlikte bugünün teknolojisindeki ilerleme sınırlarını aşarak tasarım hedeflerine ulaşmalarında mımarlara yardımcı olmaktadır. Taşıyıcı sistem dışında mimarların dikkate alması gereken diğer bir konu da formdur, çünkü form herhangi bir binanın hem içini hemde dışını etkilemektedir. Bu nedenle, bu çalışma üç boyutlu blob, sıvı (liquid) ve biçimsiz (formless) mimaride form ve taşıyıcı sistem konusunu analiz etmeyi amaçlamaktadır. Bu tezin amacı farklı çeşitleri olan yapım biçimlerini ve teknikleri biribiri ile ilişkilendirerek şekilsiz mimariyi elde etmenin nasıl mümkün olduğunu analız etmektir. Buna yaparken kubbe, kabuk, ızgara kabuk, şişme ve membran sistemleri dikkate alınmıştır. Diğer bir deyişle, taşıyıcı sistem ve form organızasyonu ve bunların arasındaki ilişkiyi bulmak için, üç boyutlu ve düzensiz blob, sıvı ve biçinsiz mimari yapılar incelenmiştir. Bu taşıyıcı sistemlerin hepside genis açıklıklı ve narin bir yapıya sahiptirler. Ayrıca, bu araştırmanın sonuçları basit veya karmaşık geometriye sahip ve hiperbolik paraboloid taşıyıcı sistemleri kullanmanın bir metodunu sunmaktadır.

Anahtar Kelimeler: taşıyıcı sistem, biçimsiz mimari, blob mimarisi, sıvı mimari

ACKNOWLEDGMENTS

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Best regard for all….

TO MY FAMILY

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Chapter 1

INTRODUCTION

In recent years geometrical forms and three dimensional designs has had dramatic developments and this development brought to the attention of architects the use of software such as CAD, CNC, CAM. Since then architects have been able to change the 2D design to 3D which this was once only a dream and an idea but now as we can see it is a reality. The result of this has guided architects to develop complex curvilinear geometries which have innovative structures and new materials. This has been the main reason of their success of creating digital design or 3d dimensional free form. With grow of population around the world, there started to be never ending demands of the customers and big developments in technology. Architects, designers and producers have decided to present the world with buildings that use innovative structures and new materials; although some pioneer design concepts would not take place because of the lack of structure and construction technology. This distance always pushed the structure designers to create new methods in order to make the complicated architectures dreams come true. Architectures have been paying a lot of attention to the concept of formlessness. For example this can be viewed in the buildings designed by Gehry where the fragmentation results from the attachment of diverse functions in individual but consistent pavilion (Mostafavi, 2002).

There are 3 different types of free form architecture include formless, Liquid and Blob architecture. Liquid architecture is the first one. It's new form that utilized lightweight material and in very thin with curved shape and structural frame panel. At first, this fluid fantasy creation with only possible in digital format, a while ago this type of architecture was unthinkable as it does not obey Euclidean geometries (Novak, 1991). For example the Sydney Opera House has been built with the help of liquid architecture. It can be seen that the wing shape roof of the Opera House, in which the panels made with GRP sandwich, the material used in this panel is ceramic tiles and the structure is reinforced concrete thick shell.

Blob architecture is the second one as it is obvious by its name it is round like a blob. This form of geometrical 3 dimensional forms is more or less similar to liquid architecture, as they are 3 dimensional and light weights. The only difference is in the form and sometimes the material used; there is not any single straight line or flat plane of any size on the structure of the building. The coverage of the structure is polished titanium panels. Blob architecture has pre-fab plastic structures and curved dimensions. The aim is to create an organic space. (Steve, 2009) "The building combines a concrete structural mass with a curved translucent double-layered skin that dramatically diffuses daylight and naturally ventilates the space." (Makovsky, 2006) The structure and form of this type of buildings will be explained later. Blob buildings have specific structural production and a different solution is required for the space systems. For example, they might have massive thin shells, panel systems, stretched membrane structures and plate irregular curved ribs (Biondi E. , 2006).

The third one of architectural analysis is involved of construction and form analysis. Digital design is all around us today. It has been boosted again by the development of 'Free Form' architecture. 'Liquid Design' and 'Blob' architecture are the result of free form development. (Makovsky, 2006). Although this short story was an introduction for undulating, inflated and conceptual form of differential calculus but, in order to understand digital design behavior we have to understand the routine styles and solution when the formality is considered. So we will categorize different types of roofs like domes, membranes structure (tensile) and shell and pneumatic with formal and technical consideration and will make a comparison.

1.1 Problem Statement

In architecture's history the main challenge was how to remove structural limits in order to create fluid and unlimited spaces. With the growth in the world's population and the ever increasing demand of customers, the new age architect always seeks to find new ideas in order to produce new, more beautiful and organic forms. For this reason they developed new technologies and software in order to satisfy these needs. First they imagined these formless shapes in their minds and then with the help of the software they virtually designed them and finally with proper calculations and analysis they build new 3dimensional design which is also called digital design and these consist of: blob, liquid and formless architecture. Moreover, these designs can each include three different types of geometries. First, the simple geometry which is simple shapes or the combination of pieces of simple shapes, the second is complicated geometries, with straight lines or positively curved or negatively curved lines or a mix and third is the hyperbolic paraboloid. The aim of this study is to analyze and determine the type of geometries that has been incorporated in the case study examples of each of the 3dimentional designs, meaning the blob, liquid and formless architecture. Also, this research will analyze the structure and form of the above the mentioned type of architecture.

1.2 Research objectives

The main advantages of 3dimensional architecture is that they are relatively concrete structural mass effective that they used in the material, wide span enclosures, double layer curve surface, naturally ventilates in the space. However, in general comparatively less attention has been paid to 3dimensional architecture. The objective of this study is to fill in this gap by extensively researching and analyzing different case study that have utilized this type of new and innovative architecture and to hopefully add value to the current body of research that exists.

1.3 Methodology

The methodology of this thesis contains the literature survey and documentary research. This research has been conducted based on articles that have published in the last 10 years and websites related to the topics of the study. In order to fully analyze 3dimensional architecture 25 case studies have been selected. All these case studies utilize not only the blob, liquid or formless architecture and this provides the opportunity to compare the different types of designs, but also the different structures and forms of each of these buildings. At the end each case study has been analyzed and the results have been compared in order to satisfy the objective of this study.

Thesis Outline:

This study is analysis and organization of structure and form relationship in 3dimensional Blob, Liquid, formless architecture including the geometries such as simple, complicated geometries and hyperbolic paraboloid.

The rest of this thesis is organized as follows:

i. Chapter 2: This chapter examine different structural behavior, analysis and classification of Blob, Liquid, formless architecture such as dome (included 11 details) shell (divided by 8 factor) grid shell, pneumatic and membrane structure. The purpose of this chapter is to development of man-made structural geometry such as simple and complicated geometries.

ii. Chapter 3: This chapter contains formal organization and geometry relationship in Blob, Liquid, formless architecture related to aesthetic design. This topic consist of basic geometric forms and their combination to form complicated ones and eventually considering their function of simple, complicated geometries and hyperboloid which this result would be the building blocks of formlessness in architecture.

iii. Chapter 4: Focused on analysis and highlights of the case studies of Blob, Liquid, formless architecture

iv. Chapter 5: Contains the conclusion

Chapter 2

STRUCTURES USED IN BLOB, LIQUID ARCHITECTURE AND FORMLESSNESS

Structure has an undeniable role in architecture which helps the architects' dreams come true. So first of all we have to consider important structure types which include dome membrane (tensile structure), shell, and grid shell and pneumatic. Each of them involved of some major types which will be explained through examples. This comparison shows us the flexibility of project in different functions with different structural potential. In this chapter discussed different types of structures and categorized the main existing construction techniques like domes, shells and membranes which have been made the complicated ideas came true. The main factor in this classification was form, and therefore, analyzed different forms with related examples. Types of structures which are studied in this chapter are:

- **Membrane action**
- **Types of structures of Blob, Liquid and Formlessness Architecture**
  - **Membranes structure (tension)**
  - **Domes**

- Cone and spherical domes
- Pyramidal and closed-up dome
- Hip domes
- Arch- pendentive dome
- Braced domes
- Ribbed domes
- Schwedler dome
- Polyhedral domes
- Lamella domes
- Network domes
- Geodesic domes

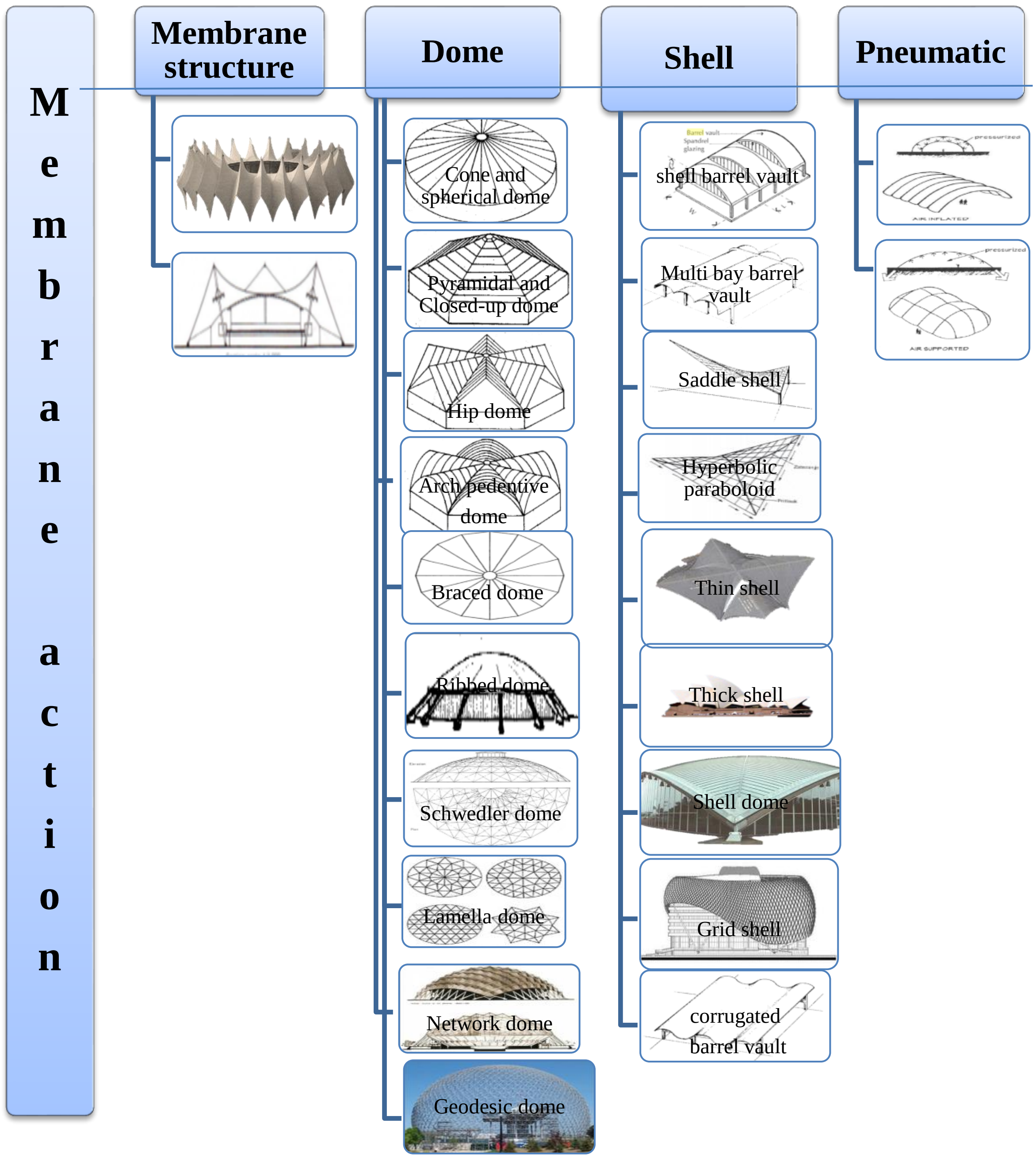
  - **Shell**

- Shell barrel vaults
- Multi bay barrel vaults
- Corrugated barrel vaults
- Saddle shell
- Hyperboloids of revolution

- Thin shell structure
- Thick shell
- Shell domes

- **Grid shell**
- **Pneumatic**

Table 1: The result of case studies analysis according to level of structure, construction and form



2.1 Membrane Action

The functions properly are thin sheets material that oppose applied vertical load in surface and providing tension stresses but we can produce compression if to give it the capacity to resist loads and preparing by pre-stressing a membrane for example sails, balloons, and parachutes (Chajes, 1990).

Among these significant inventions, an ideal membrane is a sheet of material so thin in compression with its lateral dimensions that it can only develop tension. Although a membrane is a two-dimensional structural element, or we can say it can only carry load by tension in all directions and can only be built out of materials with good tensile resistance, such materials include sheet metal, pre stressed concrete, reinforced plastic, and fabrics. In particular, plastic fabric, such as those made of nylon or reinforced by glass fibers (Salvadori, 1981).

> "Another important factor about these type of structures are membrane structures are positively thin (to decrease the whole membrane weight in order to reduce earthquake damages) and curved that they take the loads mainly in axial action the geometrical tensile membrane force method comparable to single cable systems, the external force action arise in flexible surface structure in pure tension reason by normal pressure. In thin shells, tensile and compressive membrane forces happen, so surface must be thick sufficient to avoiding buckling. If membrane is turned over, it becomes a shell in pure compression and compressive membrane when its pre stressed. It's means that all domes are a type of membrane (Schueller, 1996)."

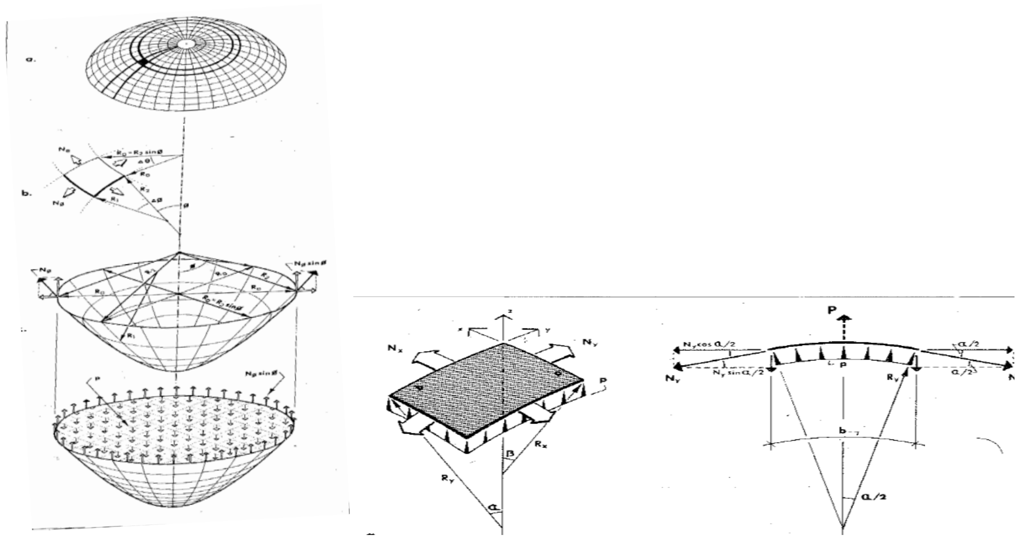


Figure1:) Uniform loads to surface in membrane forces b) Membrane body (Schueller, 1996)

2.1 Membrane Structures (in tension)

The modern structural system has being flexible, light weight and easy to form is membrane (tension) structure or fabric structure with a thin and flexible surface and high rigidity membrane materials such as PTFE, PVC or ETFE, which is generally supported by another tension or compression, or bending structures such as steel columns or high strength cables or space truss structure but the beautiful shape of three-dimensional structure, that transmits loads through tensile stresses only in the membrane surface was expanded in the middle of 20^{th} century. This structure usually used as roof as they can low cost and acceptably be stretched to large span and the idea of as an umbrella and produce tension in various ways, related on the size of the space that necessities to be covered. Due to its characteristic assemble of numerous buildings such as theatre, stadium, exhibition hall, swimming pool, or a rest area's awning in a garden or beach, exhibition hall, side walk's awning of a hotel or mall, or lobby's roofing, plus for roofing at an entertainment center, etc. (Supartono, 2011). Describing manufacturing process of this fabric structure is below tension, can take any form cause of being pulled in opposing directions, however is mostly founded around three forms, double curve barrel vault, the Hyper (Hyperbolic shape) and the cone. The membrane structures are constructed to rain, maintain wind pressure, natural ventilation, and solar radiation and implicated minimum structural support and temperature swing also performance as shading systems or atrium roofs, skylight, shelters (Maria.R, 2010).

Figure 2 shows the roof of Riyadh has been opened in 1987 and enclosed by 50.000 m tensile membrane umbrella roof with a vertical central mast and a couple of hanging and steadying cables, which are place below pre-stress by a midpoint ring cable. There are three elements has been created in structural form, the edged by ridge, catenary cables, membrane units that made of PTFE-coated glass fiber-fabric and protect people to sun shading protect and rain. The roof contains 24 membranes column and Each of the 24 membrane units involve of four different membrane parts (Schlaich, 1989).

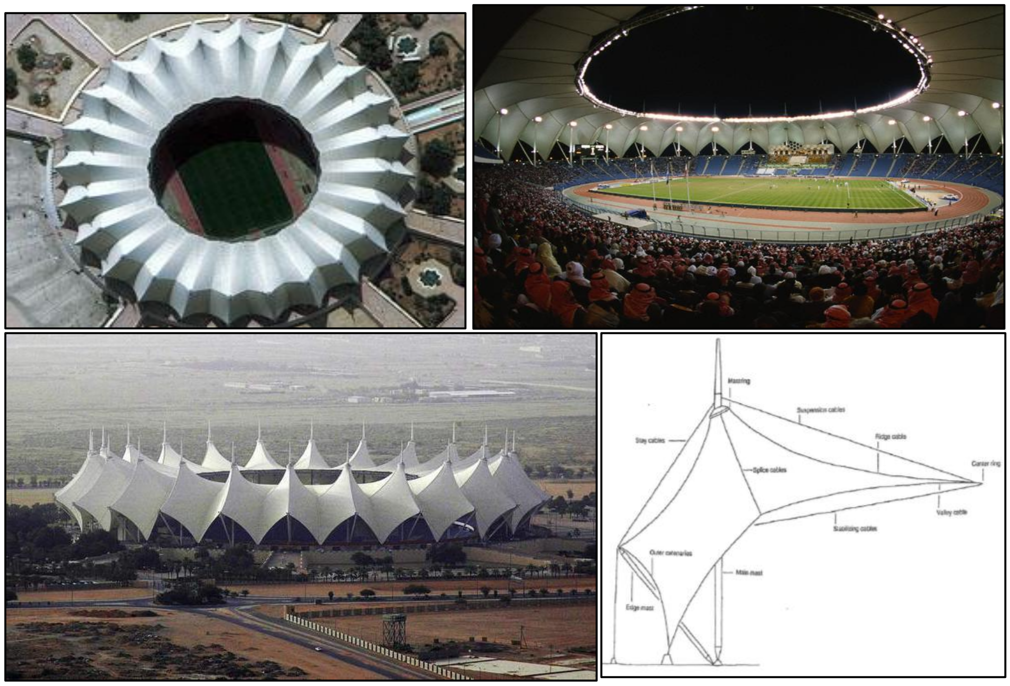


Figure 2: Types of central membranes, the Roof of the stadium in Riyadh, Saudi Arabia (Schlaich, 1989)

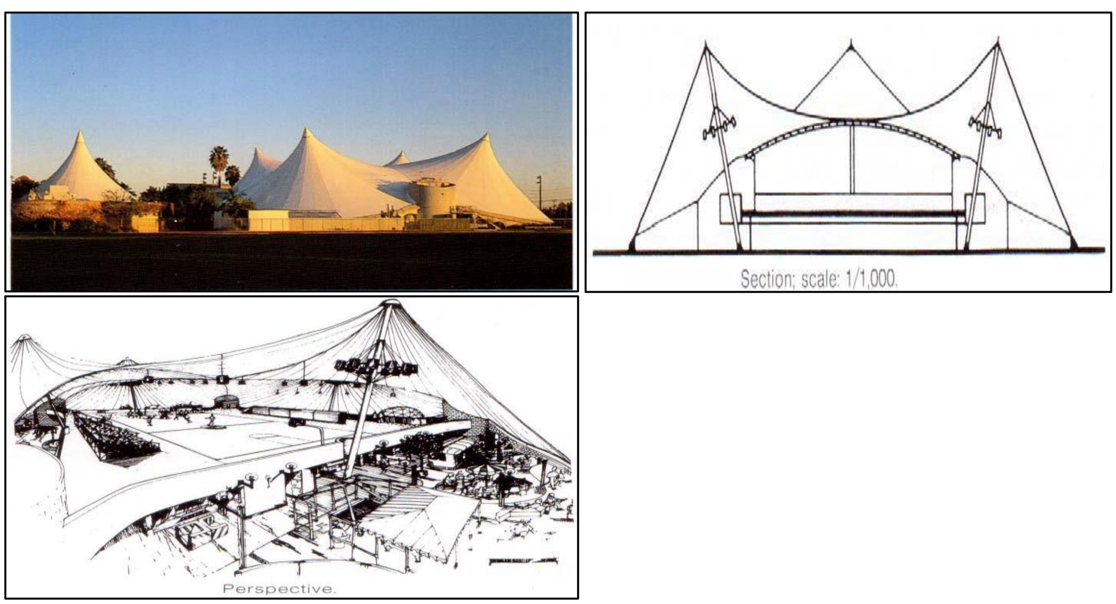


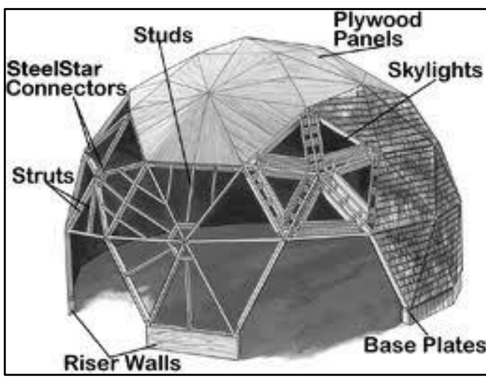
Figure 3: The Campus Center, University of La Verne – La Verne, USA, 1973 (Tian, 2011)

The University of La Verne (Figure 3) has art center and sport facilities such gym. The designer used new structure membrane structure, within this structure, a first floor is training part and a second floor gym. Four cone formed structure designing at a 15 degree angle with four masts accompany form organized to framework the roof. The cables can be support with attached to the both the concrete foundation ring and the masts on the outer sections. A recently created PTFE coated glass fiber fabric makes up the membrane surface that covers this structure (Tian, 2011)**.**

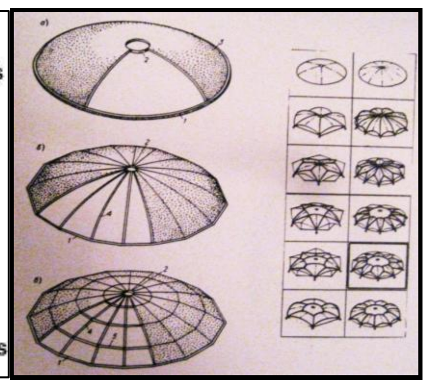
2.2 Dome

A dome is an ancient architectural structure that is very similar to a balloon cut in half and can be built with different materials. In this structure is circle or polyhedron in flat surface, the roof shape symbolized to centric upward steep slope roofs with vertical axis or as multiple shells with centrically axes of equilibrium. They have the shape with negative Gaussian curvature (rotate surface in opposite sign) in upper part and positive Gaussian curvature (rotate surface in sign) - In lower part. A variety of aesthetic form based on a circular or polygonal plan , they all conform of straight or curved ribs, at the top linked with rectangular cross-section straightly or by the ridge bearing ring and carried at the lower end by the ring beam ahead the walls (or by the foundations). The circular or a polygonal form depending on the plan shape, consist the upper and lower supporting rings. The stresses like compression loads convey the weight of the roof surface to the supports also horizontal forces (Sinan, 1988).

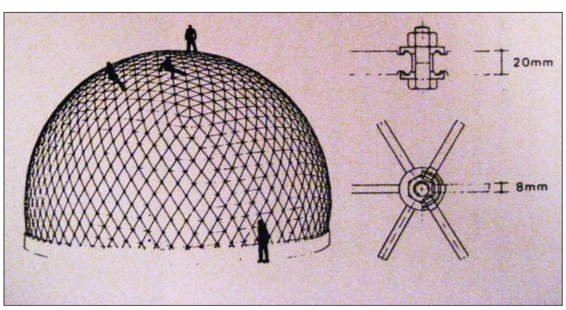
Besides all these, for primary of ancient domes mainly the buildings are, mosques, temples and ancient monuments in most cultures.A simplest form of the dome, is a half sphere, but it could be based on an ellipse, parabola and hyperbola with two categories including single curved surfaces weaker than double curvature shells. The weight of the structure in domes related to its thickness to span ratio (Schueller, 1996). “If there are so many individual cables, approximates to a thin-shelled dome. By reasoning in this way we can see that such a structure is capable of carrying a variety of distributed loadings by membrane action, that is, by internal forces which lie everywhere in the surface of the thin shell and are uniformly distributed over the thickness of the shell” (Francis, 1980, pp. 167-170).



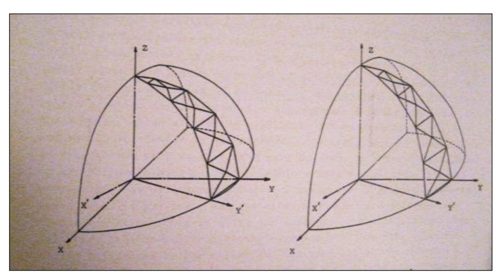
a) Skeleton of dome structure



b) Reinforced concrete domes



c) Geodesic dome



d) Steel dome

Figure 4: Skeleton of dome structure (Raunekk, 2010) Types of domes (Sinan, 1988, pp. 145).

2.2Types of Domes (Both Structural &Formal)

2.2.1 Cone and Spherical Dome

The shape of the cone, only to some extent curved ribs along its downward segment, form in plan of stable width and changeable length the consistent roof loading, therefore producing mostly compression and letting this particularly light structure (Schaller, 1996).

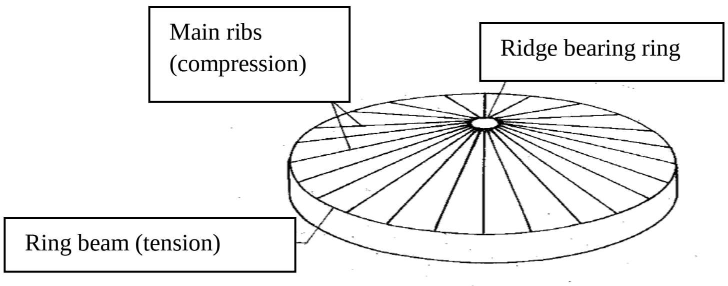
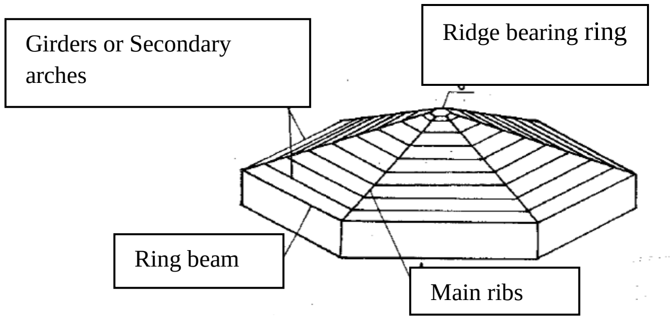


Figure 5: Detail of Cone dome with main ribs, ridge bearing ring, ring beam (Sinan, 1988.pp148)

2.2.2 Pyramidal and Closed-up Dome

The shape are different, octagonal or hexagonal and square plan corresponding of equal number of ribs and equivalent to the length of roof panel , therefore length of roof panel is determine by the slope (Sinan, 1988).



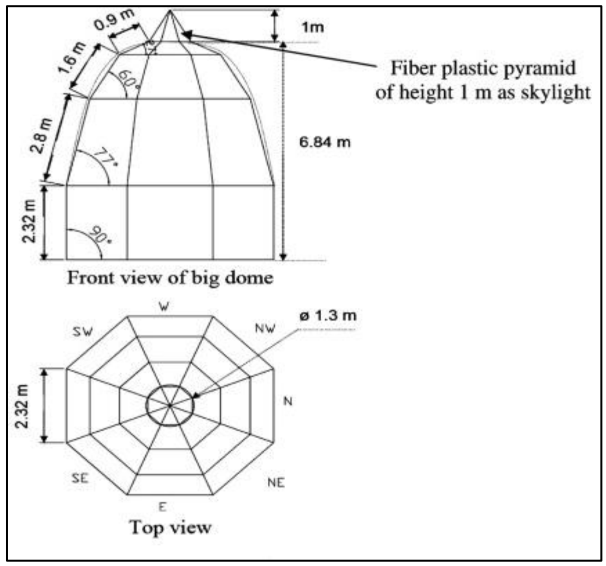


Figure 6: Details of pyramidal dome. (Chel, 2009.pp89)

2.3.3 Hip Dome

The shapes are same of pyramidal and closed-up domes, square, hexagonal, or octagonal on plan. Beside the adequate number of ribs they have as many horizontal ridge girders with their one end on the ridge bearing ring and the other on three-hinged triangular arches placed along the axes of external walls. Secondary beams are fastened to the ribs and girders, bearing panel similar of those of the pyramidal dome (Sinan, 1988).

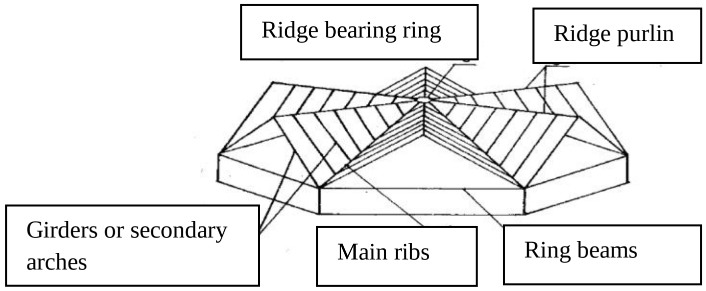


Figure 7: Details of Hip dome (Sinan, 1988.pp403).

2.3.4 Arch- Pendentive Dome

The form of the plan is same but form of ribs is curved with circular cylindrical surface with horizontal load bearing with two-hinged arches roof panels (Sinan, 1988).

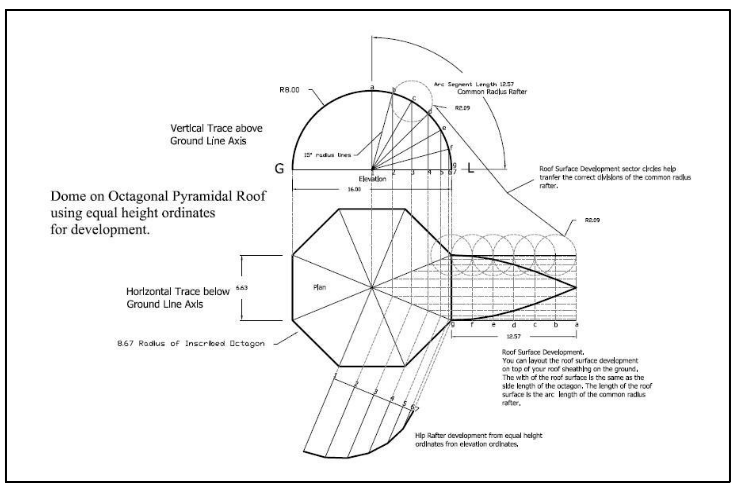


Figure 8: Dome on Octagonal Pyramidal Roof using equal height ordinates for geometric expansion (l'Orme, 2011)

2.3.5 Braced Dome

The simple pattern in the construction methods are curved members stands on a surface of revolution includes ribbed dome or straight members with their connecting points stands on such a surface includes polygonal in form with horizontal rings consist in welded steel also the other example is space grid dome created as two or three way double layer or hexagonal grids with large spans (Stroud Foster, 1976).

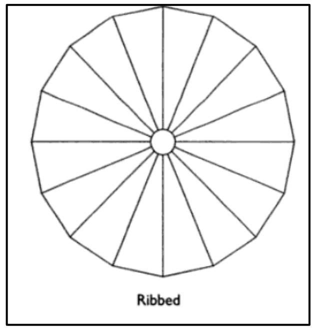


Figure 9: Braced dome (Al-Nageim, 1998.pp 52)

2.3.6 Ribbed Dome

Their span range is around 150 meters the material use are concrete and timber with easy assemble and fabrication, arches are approved in a radial manner and laterally supported at the top by a compression ring and at the bottom by a tension ring. The inner trussed elliptical arches of nearly uniform depth (Sinan, 1988).

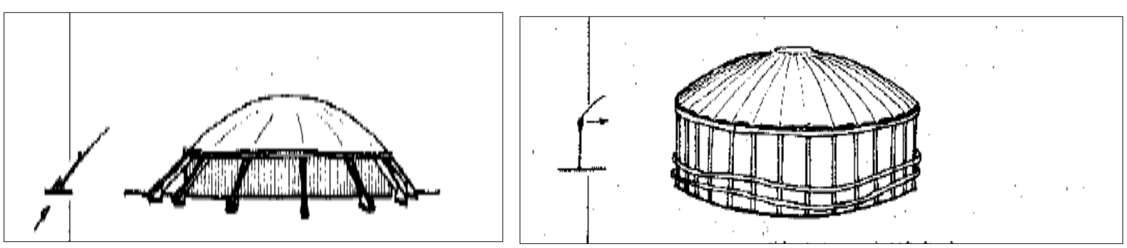


Figure 10: types of ribbed dome: a) Timber ribbed dome b) Concrete ribbed dome (Schueller, 1996.pp 143)

2.3.7 Schwedler Dome

For the state of a rectangular grid model, where the ribs and rings are axis to each other, the roof covering may give the essential shear stiffness below asymmetrical loading.

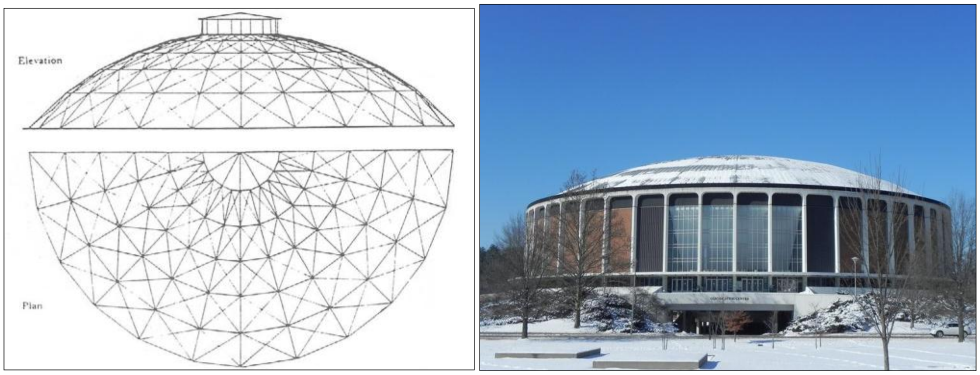


Figure 11: a) Types of schwedler dome (Sebestyen, 2009) b) schwedler dome of the Convocation Center of Ohio University. (MLB Corporation, 2012.pp 152)

The convocation center Ohio University is one of the lightest steel dome structures in the United States. The dome roof made of steel supporting by 48 concrete columns with three hoop beam and resist by a concrete ring girder as well as a spider web of radial cables extending horizontally across the dome (Whitaker, 1969).

2.3.8 Polyhedral Dome

The forms may also be generated by joining horizontal (or spatial) polygonal rings (which may have different shapes at the various layers) with spatial radial arches; the resulting rectangular surfaces are braced with diagonals.

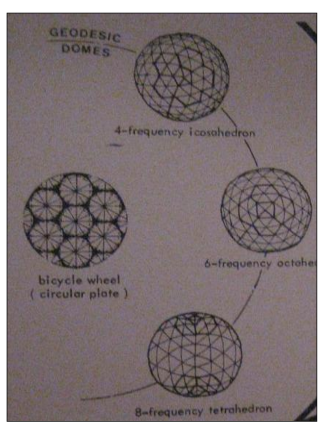


Figure 12: Types of polyhedral domes a) bicycle wheel (circular plate) b) frequency I icosahedrons c) frequency octahedron d) frequency tetrahedron (Schueller, 1996)

2.3.9 Lamella Dome

For large span domes, the lamella system is frequently used because of its even stress distribution and primarily axial member action. A lamella style frame consists of short steel members (lamellae) hinged together to form a crisscrossing pattern of skewed parallel arches. The lamella style frame extends to three dimensions for form space trusses, such as that used in the Louisiana Superdome in New Orleans.

For example the largest steel dome of Louisiana Superdome with a span 83meters and Constructed with welded steel trusses consists of 12 main radial ribs connected by 5 concentric rings; the multi- ringed frame dome diameter is 210 meters (Schueller, 1996).

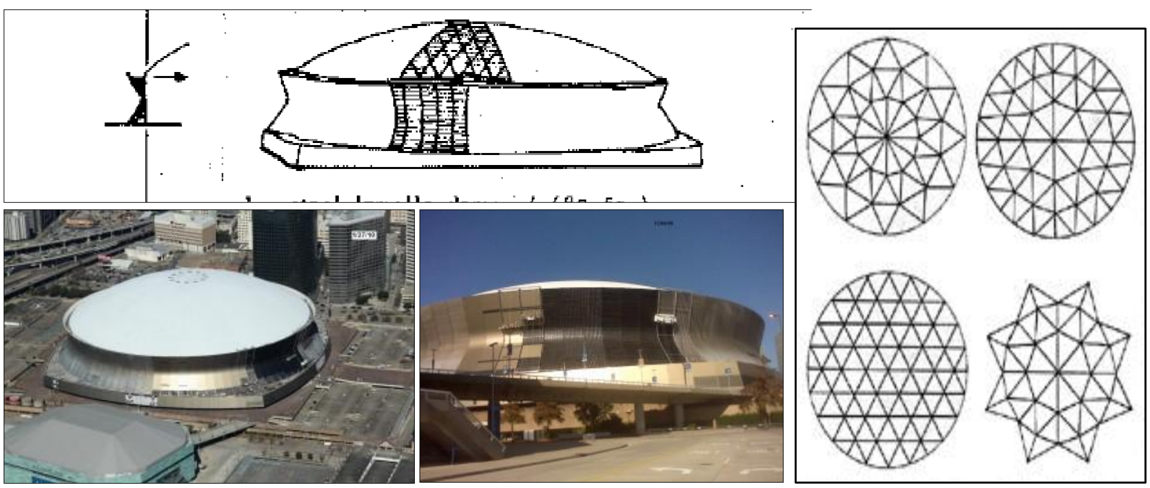


Figure 13: a) Louisiana Superdome in New Orleans b) Types of lamella dome, steel lamella dome and concrete lamella dome c) plan of lamella dome (Schueller, 1996.pp 161)

2.3.10 Network Dome

Including lattice intersecting ribs form a network; most common are two-and three-way grids. Grid domes have been produced not only over round but also over rectangular and hexagonal areas.

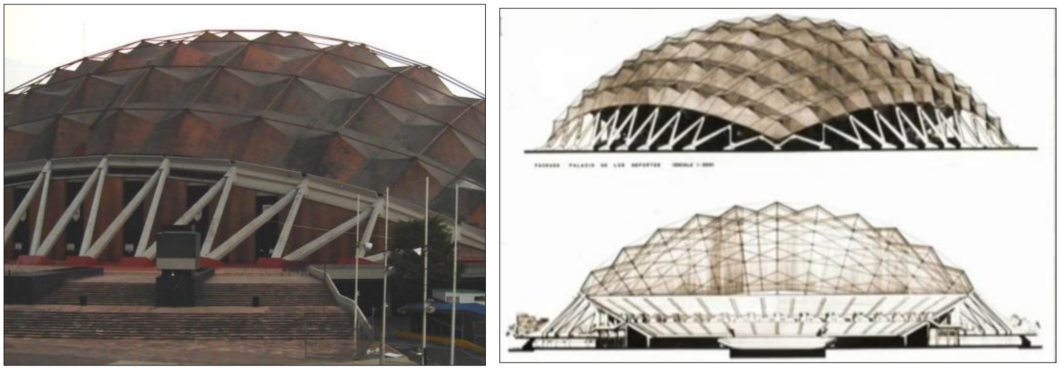


Figure 14: The sports palace in Mexico City designed by Felix Candela (Luca, 2011)

The Sports Palace in Mexico City consists of 22 intersecting trussed steel arches spanning 433 meters. Two way frames on nearly square grid are covered with a triangular mesh of aluminum tubes that form a hyperbolic parabolic surface, which is covered with two layers. Plywood and a copper membrane the dome rest on vertical concrete walls and columns resists outward thrust due to the arches.

2.3.11 Geodesic Dome

Produce extremely light skeleton structures that are very stiff and rigid, enclosing a large area without need for internal supports. Due to the light weight, the round shape of the dome perimeter, and the generally uniform load distribution of geodesic dome structures, deep foundations are not normally required. Including single-layer framing, double layer space trusses, and stressed skin construction; are three way grid structures where the primary radial ribs of the upper dome portion lie on the great circles of the sphere. In other hand, the geodesic dome design includes metal ribs placed in a triangular or hexagonal pattern that lie on the great circles of a sphere, called geodesic lines. Most commonly, this design utilizes aluminum, such as that found in the Poliedro de Caracas, in Venezuela shown in fig 15. Shell vault is the term for this design when constructed from aluminum tubes (Underwood, 1998).

The Advantage of Geodesic Dome: Geodesic domes are economical in terms of material. It means that the use less materials and also self-supporting, they don’t need internal column for support. Moreover they have a greater weight-to-force ratio that leads to stability can be force in two different reaction which include compression and tension. Geodesic domes are made of triangles based on pentagons and hexagons; lamella domes can be given in other patterns (Underwood, 1998).

Figure 15: Montreal’s Biosphere in Canada (Meyer, 2005.pp 326)

The Figure 13 mentioned dome is 60.96 m high (20 stories) and (76.2 meters) in diameter. The structural foundations of Fuller’s domes regardless of the size all have three-dimensional units, curved to fit a specified arc. As it can be viewed in the pictures above, they also have a triangle on the outside, hexagonal on the inside. Moreover, in order to spread the weight over the whole surface the triangles are connected together (Meyer, 2005). It consists of three quarter sphere with a 76meter and a height of 62 meter. The shell is a thick double-layer space frame with the tubular members slotted at their ends so that they can be pin connected to cast steel spider connectors, which have central hubs and 12 radial arms for the outer layer (Schueller, 1996).Considering the above in formation, geodesic domes can be found in many common types of buildings such as houses, sports stadiums, or even temporary structures. Aluminum is the most common material for this structure (Schueller, 1996).

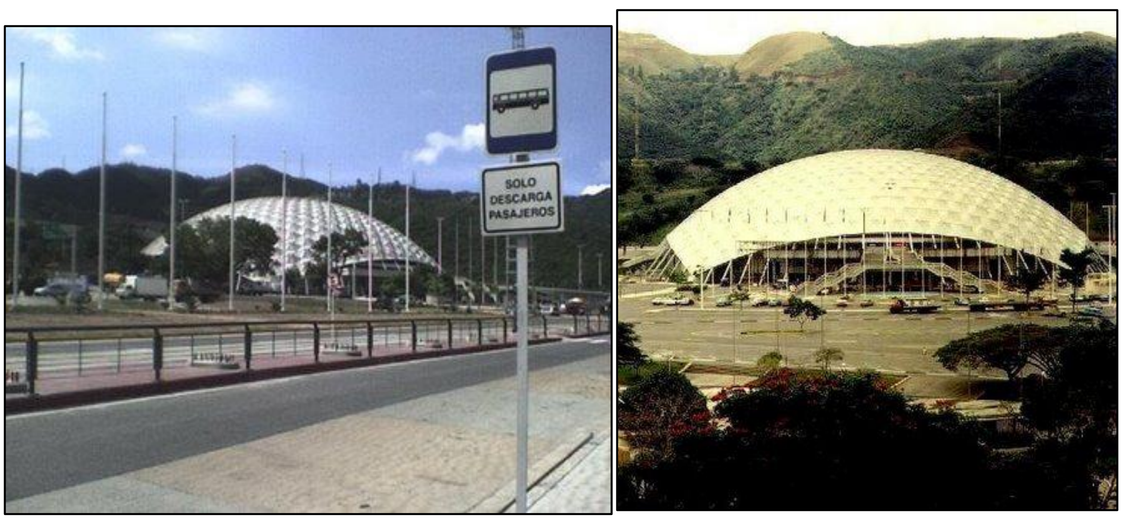


Figure 16: The poliedro de Caracas, Venezuela (Alejandro, 2008)

The Poliedro de Caracas, Venezuela is one of the examples of geodesic domes with large span and largest aluminium domes in the world. Its two layer consist of triangular exterior grid and a hexagonal interior one (Schueller, 1996).

2.4. Shell

Shells are construction systems with very thin curved membrane, achieved by given that limit at the edges such that bending stresses in it are so tiny. The membrane applying stresses within thickness .This thickness is related with its shape (Stroud Foster, 1976).

On the hands, shell structures can be efficiently and economically and strongly used in various fields of engineering and architecture. Large span have been easily covered by reinforced concrete shells. Shell structure has small thickness with two-dimensional curved structure and geometrical properties of their surface (Galant, 2009).The main characteristic of shell construction is three dimensional geometrical curved solid slabs and they are very economic. Membrane performing as stressed covering surface.The capacity of carrying the load depends on form of the shell (Bradshaw, 2002). Shell can be used of any material including wood, steel, plastics to reinforced ceramic shell, aluminum, but the ideal material, which can be used in shell structure is reinforced-concrete (concrete shells of large span have pre stressed elements and their deflection should be controlled). It means that they can be given shape easily also they don’t need another covering material (Schueller, 1996).

2.5 Types of Shells

2.5.1 Shell Barrel Vaults

They are called long span vault shell.The width of a long-span barrel is usually not more than 12 m with a maximum practicable width of 15 m. The maximum economic span is about 30 to 45 m (Stroud Foster, 1976). And very useful in shell structure; because they use minimum material and long distance span. To decrease stresses and thicknesses in the crossover direction mainly they are extremely proficient structures, because they use the arch forms is shown in figure 16. The structure below is a single barrel vault with edge beams (Ketchum, 1997).

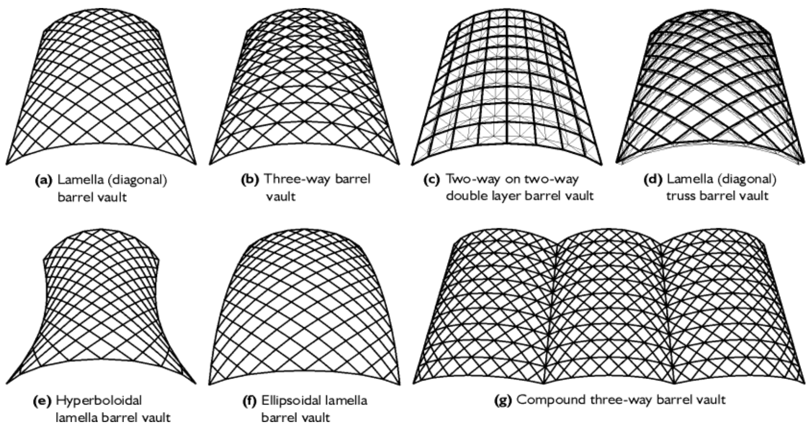


Figure 17: Examples of cross-section barrel vaults (Joseph, 2012)

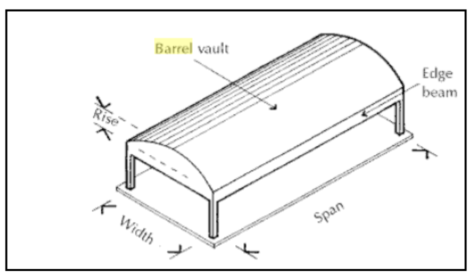


Figure 18: Detail by reinforced concrete long span barrel vaults (Stroud Foster, 1976.pp 232)

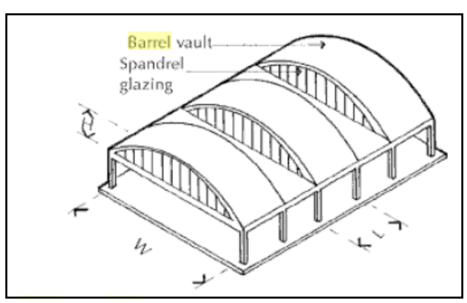


Figure 19: Barrel vault shell roof construction (Emmitt, 2006.pp 252)

2.5.2 Multi Bay Barrel Vaults

If more than one barrel vault and more than one span put side by side although, width distance is smaller than or half the span and the rise about one fifth of the width with minimum thickness. The stiffeners and stability are above the roof, so there are avoiding the interruptions inside the shell (Emmitt, 2006).

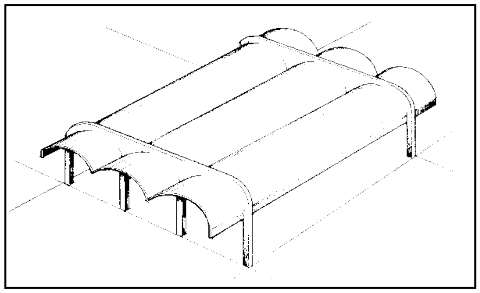


Figure 20: Multi bay barrel vaults (Ketchum, 1997)

2.5.3 Corrugated Barrel Vaults

As we can see in this figure shown the top of the roof has alternating concave and convex circles of the same radius in this shell structure.

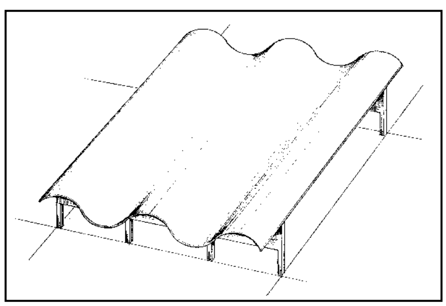


Figure 21: Corrugated barrel vaults (Ketchum, 1997)

2.5.4 Saddle Shell

The structural system of different reaction from edge members can be achieved by load is carried to edge members and the shape has undulating outer edge .In this interaction force there are different parts of ending points, one part have high points and create tension stresses and the other part created low points, compression stresses between them. The edge members convey these loads to bearing, mostly by axial compression. Horizontal components of bearing reactions must be absorbed by ties or by fixed bearing (Bradshaw,2002). These are much stronger than cylinders against buckling because the tension along the upward curved fibers stabilizes the downward, curved, compressed fibers. Hence the buckling load for saddle shell supported on arched end-stiffeners is safely approximated by that of a cylinder with a radius of curvature equal to that of the saddle shell at the stiffeners (Salvadori, 1981).

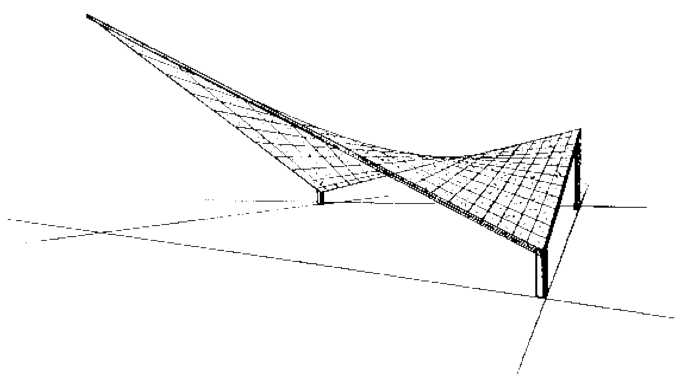


Figure 22: Saddle shell form (Ketchum, 1997)

2.5.5 Hyperboloids of Revolution

Hyperboloid roof has four walls with different heights and slope with large spans, for example if we have one flat sheet and rotated in the same axis with different parts and give the doubly curved surface with negative curvature. The material used is brittle materials like concrete. Negative curvature shell is in tension (Bradshaw, 2002).In order to achieve hyperbolic paraboloids, the surface simulation looks like a saddle because those in which the curvature is conflicting in sections cut at right-angles called doubly-curved slabs or shells (Stroud Foster, 1976).

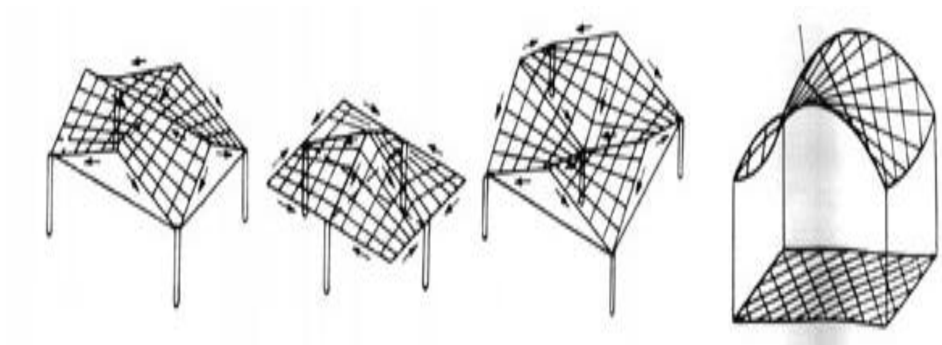


Figure 23: Hyperbolic paraboloid different model (Velimirović, 1998.pp 628)

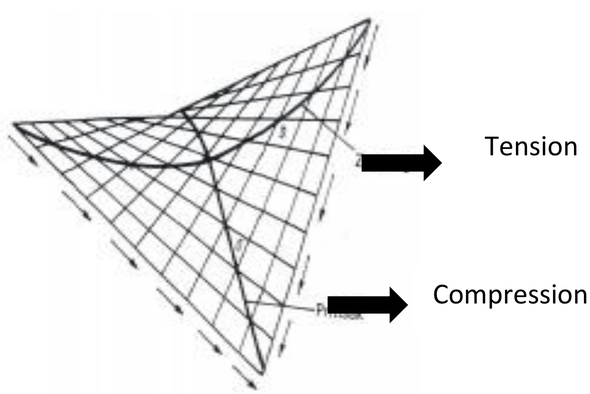


Figure 24: The tension and compression in Membrane stresses of Hyperbolic paraboloid structure (Velimirović, 1998.pp 629)

In terms of the advantage for three-dimensional forms included shells, doubly curved slabs and folded slab with long spans reinforced concrete is used in beam and slab form (Foster, 1976).

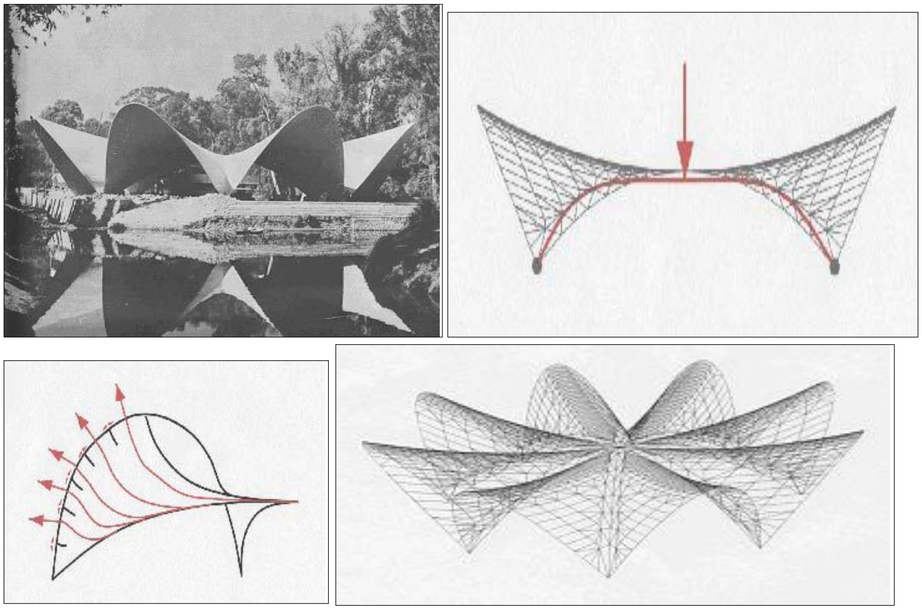


Figure 25: Restaurant Los Manantiales (Burger, 2006.pp 4)

The greatest form Los Manantiales is one of the examples of hyperbolic parabolic saddles, the symmetrical shape is an eight-sided groined thin concrete vault shells arrange of four intersecting multi span roof. The double curvature shell has edge with ribs have small stiffness in normal direction. The bending and deflection in groined vault cause of load bearing in surface; the free curve edge has rotating in upward surface and downward surface

Thin and Thick Shells and Shell Dome:

There are many different ways to classify shell structures the common consideration is the shell thickness. Two categories; Thin and Thick Shells have defined shells.

2.5.6 Thin Shell Structure

Thin shells are form-resistant structures with adequate curvature that take loads principally in membrane action that is, in pure axial and shear action along the middle plane of the shell. In difference to pre-stressed tensile membranes, positively curved thin shell to resist load in pure compression (ideal situation), but generally shear and tension do occur; bending stresses are usually restricted to the boundaries" (Schueller, 1996). Thin shells, especially if they are curved in two directions, like a dome, rather than in one direction only, like a barrel vault, have great capacity for carrying different types of distributed loading by membrane action" (Francis, 1980). Loading condition and certain geometrical parameters are boundary condition, height and span. Usually material can be used as reinforced concrete (Schueller, 1996).

Figure 26: Olympic ice stadium roof at Grenoble in France (Say, 2006)

Figure 24 shows one of the examples of thin shell structure, The Olympic Ice Stadium roof is hexagonal shape consists of cylindrical shells with huge reinforced concrete cover and span of 95m and 65m. The technique based on new construction methods which are the large double shell on four supports and only two abutments keeping and supporting of two smaller ones the thickness of double shell is 1.3 m. It is thick because the upper and lower shells are each 6cm.The materials which were used are concrete, aluminum and steel (Schueller, 1996).

Figure 27: TWA Terminal (1962) (Lang, 2004)

The roof of TWA Terminal consists of four cantilevering, wing like shells each of them assembled by edge beams and support by two Y-shaped buttresses that are steep along the direction by resultant load action with spherical, lightweight concrete shell segment. Each shell unit only rest on two abutments. Skylight spans gap between the shells along the interior edge beams near the center of the roof, the interior edge beam consist in center of the roof and connecting common plate at the intersection of the four units (Lang, 2004).

2.5.7 Thick Shell Structure

Providing bending stiffness and the thickness of surface is bigger than thin shell structure. Shear deformation exists. In Thick shells, the surface is thick enough to carry bending moments and normal shears, in addition to the forces carried by thin shells (Schueller, 1996).

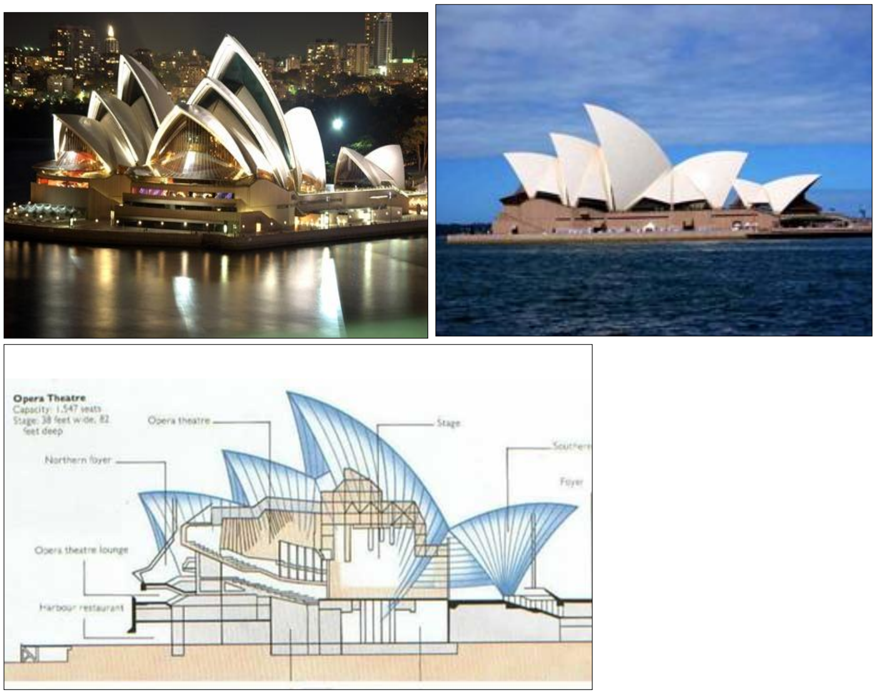


Figure 28: Sydney Opera House in 1957 (Valley, 2010)

The Sydney Opera House was designed in unique shape and construction. The roof of this building is consisting by huge different size modular units precast reinforced concrete shell vault with their white glazed tiles skin in upper part of the building and the base was clad produced as prefabricated concrete elements with exposed granite aggregate. Therefore, the precast concrete panels shell vault supported by precast concrete ribs rising to a ridge beam. Investigation of the podium paces rest on pre-stressed folded concrete beams spanning 49 meters (Wales, 2006).

2.5.8 Shell Dome

Shell domes take consistent vertical loads as radial arches in compression in the upper part of the dome cause of the arches, in turn and attached together by horizontal rings and lower part have tension (Schueller, 1996) .“Shell domes constructed with large span 45m or more, the shape is spherical dome with concrete material. To avoid horizontal thrust in circular shell domes a ring beam or ties should be provided at the base of the dome to take up the thrust” (Stroud Foster, 1976.pp 302).

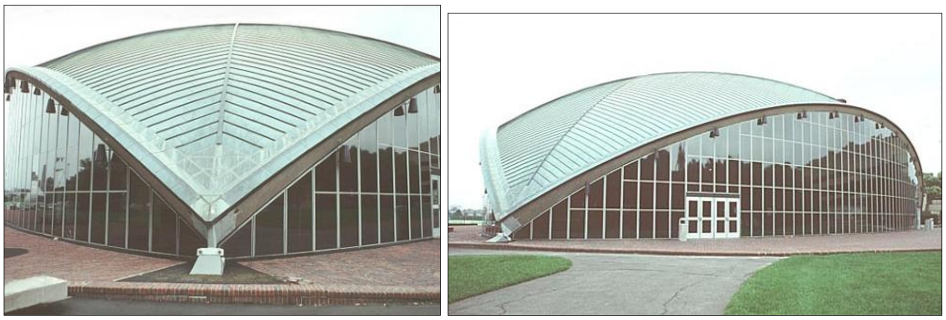


Figure 29: Concrete Shell roof structure Kresge Auditorium, MIT Campus Architecture (MITArchitecture, 2011)

In Kresge Auditorium roofs are generally shaped like a curved shell and assemble to larger structures architecture, the roof construction in general shell structures by slight build with shell elements. Thin shell is a shell with a thin dimension; the deformations are not disproportionate to the thickness. Shell structure of the various structures such as bending plates that are flat. Shell membrane bending deformations, when the stresses that make the structure from the shell of a slender solid roof made.

Kresge Auditorium concrete shell roof structure looks so elegant thin shell structure, one-eighth of a world growing at a height of 15.24 meters, and decided by the vertical glass walls, so that it reaches the country, on three points. 1200 tons of weight of the roof structure of the concrete composite shell with innovative technology. The architecture of the concrete shell with a conical roof at the edge of the roof, designed the building, when viewed from the top of the construction of the roof structure, viewed as a clam (MITArchitecture, 2011).

2.6 Grid Shell

Grid shells often originate as structures that have the form and stiffness and strength of a double curvature shell with equivalent tensions below pre-stress and small thickness but they contain of a grid and not a continuous surface. The shape constructed by rigid and lattice pattern can cross large span with a low amount of materials. They can be made of aluminum, steel, wood (very low weight and density and economic to use) or even cardboard. The advantage of this structure is easy to manufacture and cost-effective method construction (Bouhaya, 2009). “Grid shell creates a rather rigid system as every element of the continuous surface is locked in by the internal stresses and transfers these to the neighboring elements” (Toussaint, 2007.pp 32). The significant concept of grid shell is manufacturing starts from a smooth surface and the straight members are modulated on ground floor as a flat mesh. The membranes are at right angles to the surface and fasten the connections and boundaries once the shell stretched it favorite, (equilibrium) shape; also the form of the structure is achieved by locally forcing (i.e. bending by pushing and pulling).(Huijben,2011)

Multihalle Mannheim is one of the examples of grid shell with doubly curved compression structure by Frei Otto and Ove Arup & Partners in Berlin. The complex contains of two main purpose halls such as entertainment, exhibition, sport activities, theatre, concert, etc. another one is restaurant.

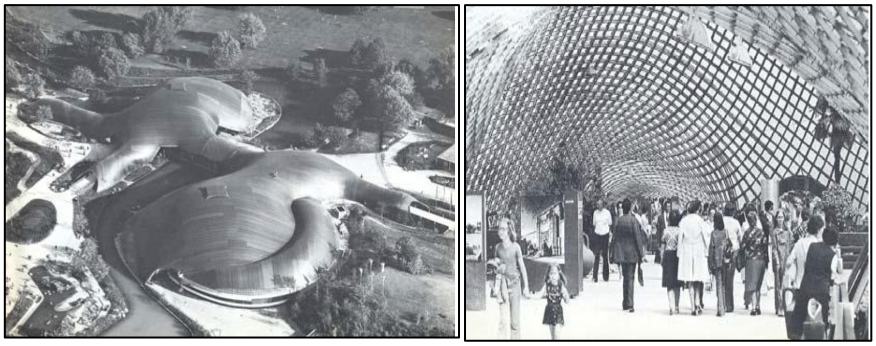


Figure 30: Grid shell roof structure Multihalle Mannheim (Toussaint, 2007.pp 34)

The complex continues and surrounded with long lengths artificial hilly landscape of the garden. It is constructed by double layered mat of timber laths have a cross section of 2500mm and the span ratio is 85m. The grid is maintained by four various edge supports: Cables, concrete foundations, laminated timber beams and arches. (Toussaint, 2007)

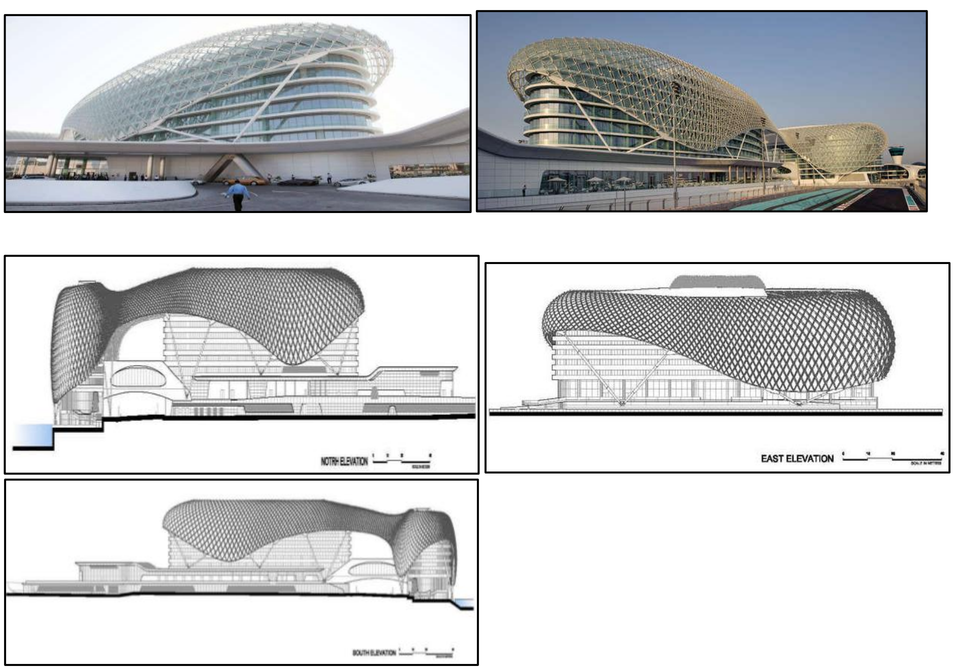


Figure 31: Grid shell roof structure Yas hotel (Singhal, 2011.pp 7)

The significance grid shell complex of Yas hotel in Abu Dhabi from UAE, has, 85,000-square-meter with 500 room and 217 m extend of sweeping, curvilinear shapes made of steel and 5,800 cover up by diamond-shaped glass panels. Grid-Shell module be able to the building architecture consist of an impressive-like curtain that covers two hotel towers and a connection bridge constructed as a monocoque molded steel body. The shining jewel-like configuration of grid shell complex creating environmentally optical properties and tectonically spectral reflections that show for the neighboring sea, sky and desert landscape providing dominant sense of place (Singhal, 2011).

2.7 Pneumatic

The pressure and compressed air like air balloon called pneumatic structures, are basically thin membrane structures has light weight tensile skinned. The types of that are Pneumatic structures air- inflated structures and air support structure with half cylinder and hemisphere shape based on membrane which carries load expanded from the tensile stresses by applying an external force which stretch the membrane stiff also if the membrane is volume enclosing, the internal and pressurization system occurred (Yellapragada, 2010). “A pneumatic structural system is a membrane structure supported by internal air pressure and stabilized by cable and ballast” (Veloso., 2010).

The combination of structure divided by two mechanisms with very various properties: A compressed air or gas and an airtight membrane, fundamentally composed of carbon dioxide, nitrogen, and oxygen can be defined by its composition, the volume, the temperature, the pressure. The membrane is in a solid formal and its properties are defined by the material (for example, the elastic modulus of the yarn, the chemical composition, the type of weaving, and the mass density of the coating) and the geometry of the principals (Wouters, 2010).The benefits of this structure are no internal column and also economic or low cost efficiently, gives perfect natural light as glowing/transparent plastic sheets are used to cover air bags, simplicity of designing and fabrication huge free space (Yellapragada, 2010). The balloon roof do not need internal support posts that might get in the way and lighter and cheaper than other structures so generally used huge area such as sports arenas, agriculture, warehouses, exhibit halls.

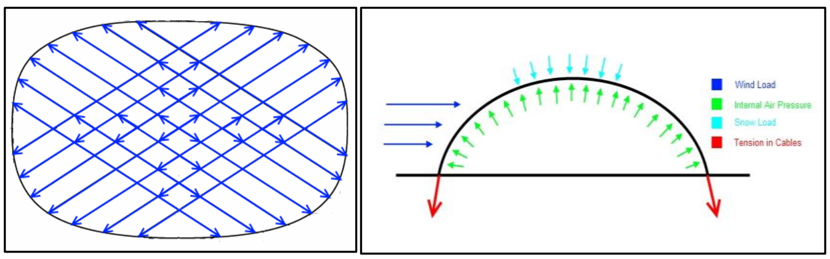


Figure 32: Construction method of Pneumatic structure (Wouters, 2010)

The details of a pneumatic structure are the doors, envelope(is a single or double membrane and at risk to outdoor wind and snow load supported by the inside air pressure), fans (essentialy capable to replace any air lost through doors or the membrane itself to keep equilibrium), cables (consolidation and securing for the envelope, produce tension to anchor the envelope to the ground) and foundation. Air supported structures it contain of single membrane have inside volume pressure of air a little higher than atmospheric pressure supporting the envelope from beneath. Air-inflated structure has air below high pressure satisfying only the supporting edge or panels and can be able to self-support (Veloso., 2010).

“In pneumatic assemblies, pressure differences between the exterior and enclosed space accountable for giving the building its form and also for stabilizing the hull. Fabric is pre-tensioned by an internal overpressure of the air” (Wouters, 2010.pp 8). This structure primarily arrangements with loads from wind, snow and internal pressure through tension. The load from the internal air pressure creates an upward and outward force on the envelope (Veloso., 2010).

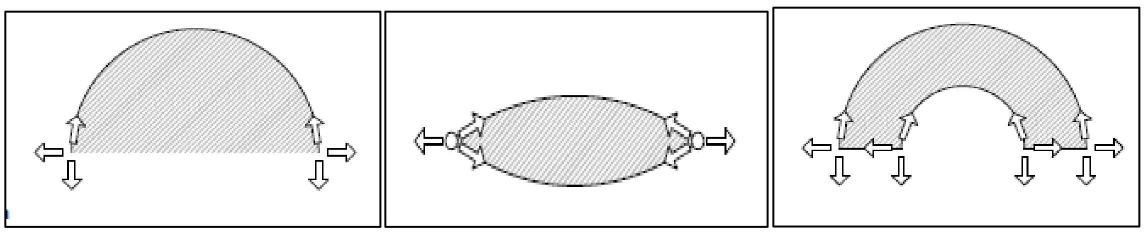


Figure 33: Tension diagrams for air-supported halls, air Cushions and air beams. (Wouters, 2010.pp 8).

Air-Supported Structures are pressure a little higher than atmospheric, gradual deflection, better spans than air-inflated and have light loads but in Air-Inflated Structures higher degree of Pressurization, pressure doesn’t straightly balance loads, buckling or folding consequences in collapse, flexibility and inflection in space also the members of that are pre-stressed and increase in tension (Nichols, 2007).

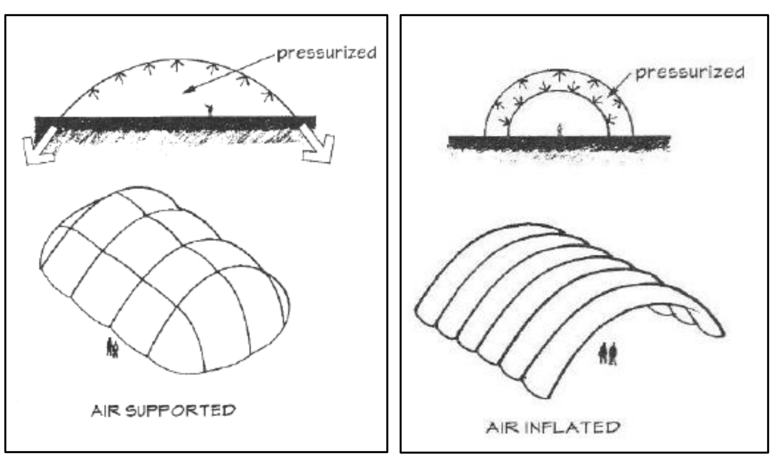


Figure 34: Air-supported and air inflated models (Nichols, 2007)

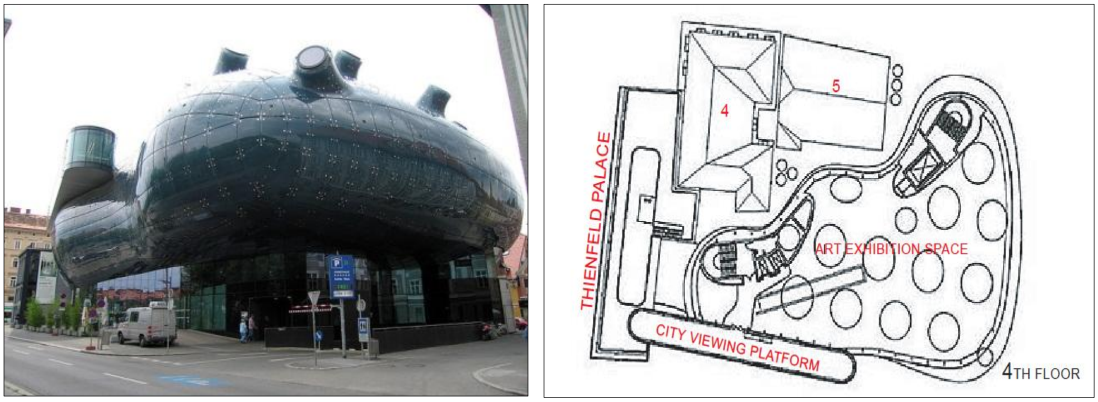


Figure 35: The Graz house of Arts (Alibaba, 2010)

For example, the Kunsthaus Graz, or Graz Art Museum has been built as part of European Capital of Culture celebration in 2003 and now is an architectural landmark in Austria. And also the exhibition plans is essential for the last four decades. The conventional exhibition context had the most effect on the unusual form of the building that the concept idea known as pneumatic. The design is consciously against the surrounding baroque roof landscape although there is integrity both in form and material for example the red clay roofing tiles with the mentioned roof landscape (Colin, 2004).

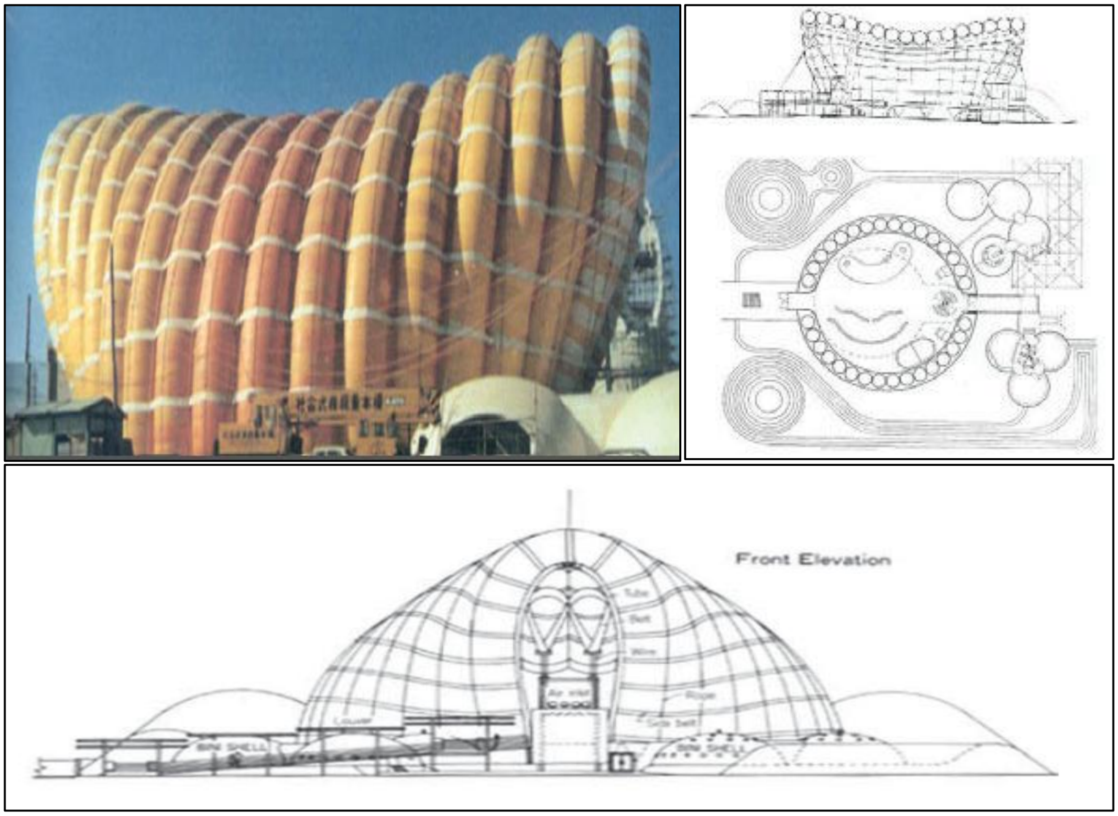


Figure 36: The use of pneumatic structures in exhibitions reached a peak the EXPO’70 in Osaka design by Murata, Yutaka in 1970 (Kristiina, 2007.pp 39)

The movie and art center Fuji company pavilion in expo’70 was type of a largest pneumatic structure; the type of structure improved the new style, anticlastic form and air-filled structure. The designing was hybrid structure with air-filled portions, held together by cable net system. The fabric used was developed in membrane tube enclosed the air and high pressure air was the compressive portion carrying loads, the surface was added coated with PVC film to confirm air-tightness (Kuusisto, 2007). The surface was additional coated with PVC film to confirm air-tightness. The shape was designing by 16 arch form tubes. The organic shape made into three dimensional geometric form organized along the perimeter of a circle having an external diameter 50m.

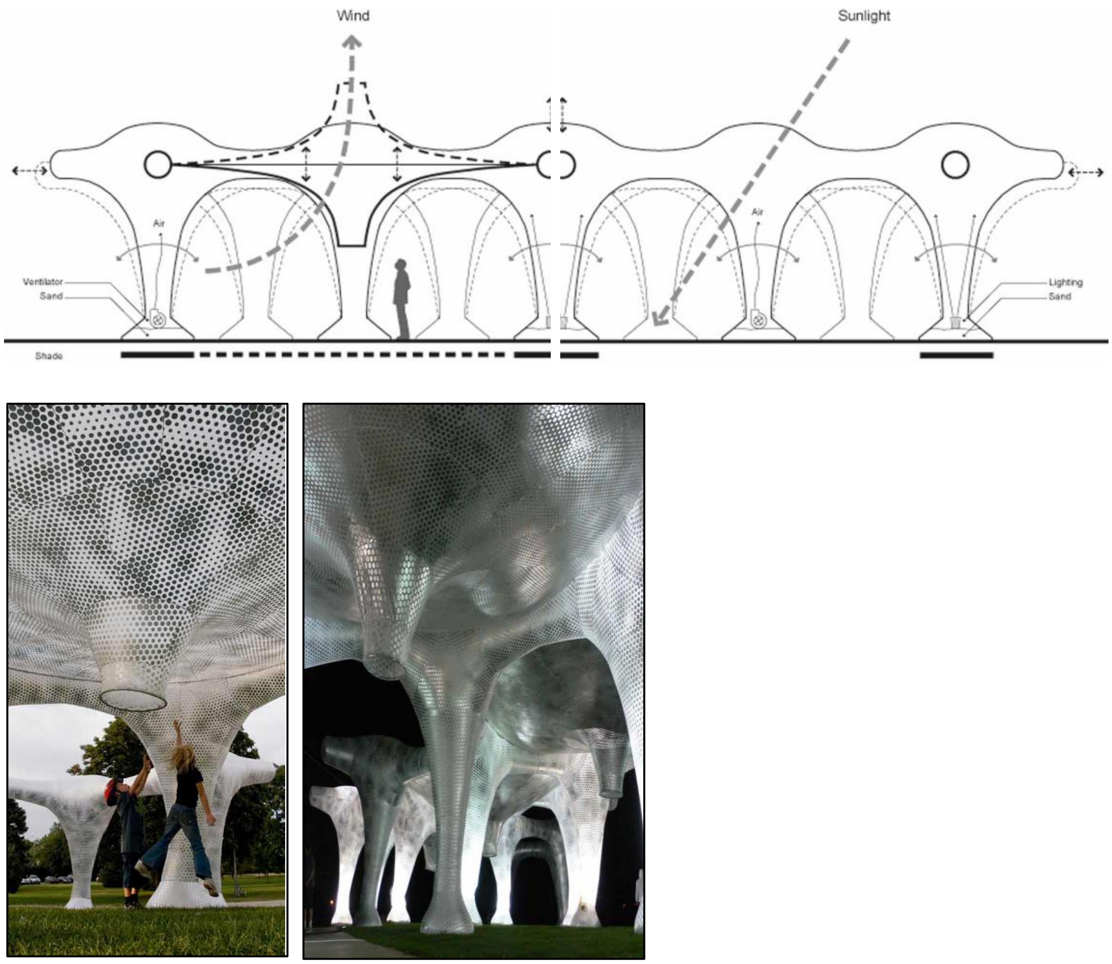


Figure 37: The forms of Air Forest - Mass Studies (Wouters, 2010.pp 43)

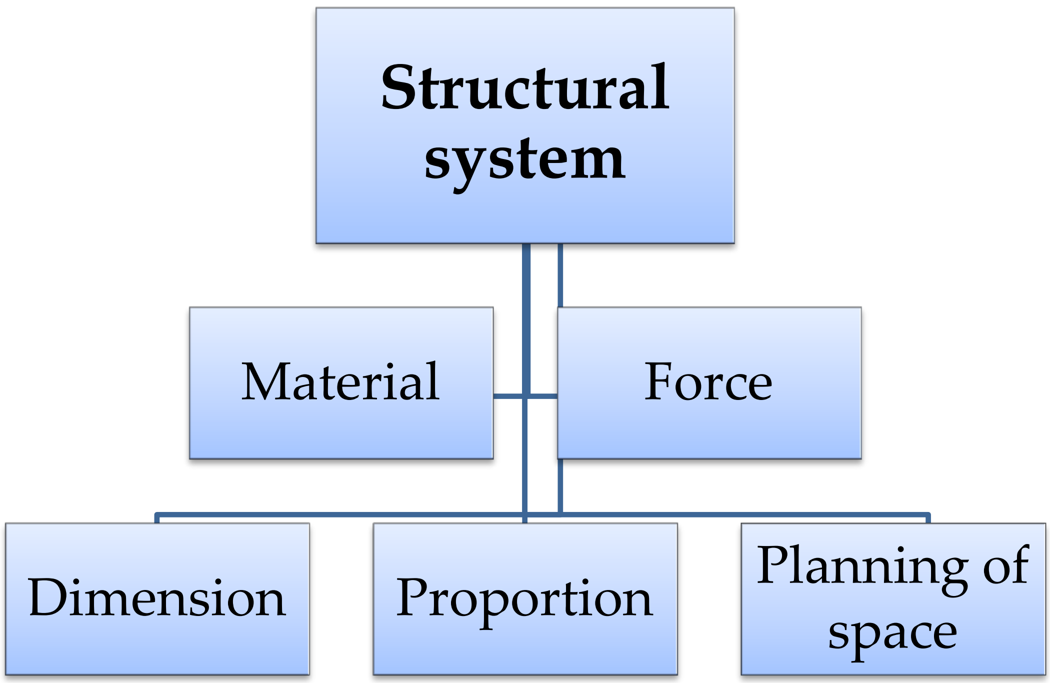
The air forest collected of 9 hexagonal canopy elements, at 4 meter height. These elements are unified as one huge part of fabric, which are then exaggerated from the 14 blowers that are situated at the base inside its 35 columns. These columns are 5m separately, and are weighed down by ground and lighting elements, which are also inside the columns, which light up at night and make available a public space after dark as well. Every 6 of these pneumatic supports form a component as they are linked in a hexagonal manner producing a circular opening from their inside perimeter (Wouters, 2010).

2.8 Result of Structures Used in Blob, Liquid and Formlessness Architecture

In this chapter started with basic concepts definition, their application and transformations in complicated forms, the evaluation of three dimensional Blob, Liquid and Formless architecture according to their structural behavior such as dome (included 11 details), shell (divided by 8 details), grid shell, membrane structure (tension) and pneumatic. Although describe of geometrical definition such as simple, complicated geometries and hyperbolic paraboloid sample and compare them with man-made architectural design.

In any case we have understood all complicated designs were formed by cut pieces and join them in an unusual way with double curvature surface. The whole procedure was moving from form to formlessness. The comparison and analysis between formal and formless examples helps to understand the differences better. The differences are more concentrated in concepts, space, facades, applications views and any other factors, which may change during this procedure. The study has intended to the comparison between all existing structures and finding the more adaptable one with this new generation of formless architectures. Although, in digital space and structure are in simultaneous and relative motion in spatial organization, both are needed to make a proper form (interior and exterior), to achieve a curvilinear shape, this is what they call formless. It is this premise that form to formless celebrates, it happens in some styles like blob and liquid architecture.

Table 2: The analysis according to structural system concept



Chapter 3

FORM AND GEOMETRY

Like a pause in a piece of theatre, space in design can speak volumes. We often hear from designers about how the use of space allows content to breathe. How this space can affect form? How is it used as a material in the design of a building? Many architects focus on what they actually build like walls, floors, windows and doors, but what is really important is the space, as it is the space that gives a different perceptive in architecture (Furnell, 1998).

Considering the spatial experience focuses on what is not constructed, in other words the space, unlike architecture that focuses on the construction. In the issues of space it is essential to consider the right medium, which is the space itself. Unlike building materials that have to be designed, managed and documented, space comes free and it is accepted as the most important in architecture, it is the space and the spatial boundaries and connections that we mainly experience rather than the material used (Furnell, 1998).

Also, the new generation architecture has aimed to enter methods for making architecture more fluid and flexible in articulation subverting the notion of shelter, house and sense of place - the building forms itself like an organism that 'becomes and un-becomes' in waves of indeterminate geometry. In this orientation all surfaces are continuous and fitted together seamlessly, breaking away from contemporary and regular architecture productions. As it struggles to escape form as a manifestation of various norms and constraints, it is as old as architecture itself. But the formlessness is also increasingly in the air today, whether explicitly as in discussions of the "formlessness" quality, or implicitly in talk of atmospheric buildings, randomized structures, and the dematerialization (or increased mediation) of architecture. No doubt part of its appeal lies in the fact that the formless is frequently found at the intersections between architecture and other fields ,this is formlessness that continues to inspire new thought and new notions of modern. Considering the Free-form surfaces have been first used in architecture by Frank Gehry especially developable surfaces, which are also called single- curved surfaces. They can be unfolded into plane without stretching or tearing (Klingmann, 1999).

This chapter aims to introduce various geometrical forms in Blob, Liquid and Formless architecture by considering the relationship between form and structural systems.

3.1 Formal Organization Concept

To articulate and define form and space we can organize the geometric basics such as, point, line, plane and volume. Such elements later become the basics of architecture: columns, planar walls, floors, and roofs.

- Columns are observable in three dimensions and are important since they are visible and space.
- Two columns can classify as a spatial membrane which can be viewed a pass way.

- The columns can outline the edges of a transparent plane when underneath a beam.
- When a wall marks off a portion of a shapeless space it divides the areas in that given space.
- Floors can be explained as an area of space that has territorial limits.
- A roofs mechanism is to provide cover for the space that is underneath it. (Ching, 2007).

The philosophies of space and form organization for architectural development are concerned with The use of strength materials and cooperation or durability and security, also the use of space (utility, function) facilities to dwellers, plus the aids of aesthetics (beauty) as well as the realized by using the principles of design is Architecture as well-known from the simple building of having only strength and function which is called an engineering structure (Salvan & Thapa, 2000).

All the elements mentioned above are essential in architectural design, since they provide form, differentiation borders and the interior space. Architects must take into consideration a number of factors when designing a building, for example, technical considerations, financial aspects, planning, the structure and construction and the class of the image and style. Moreover, it is imperative to consider the physical framework and the external space of a building. Additive forms can develop and join with other forms by combining with separate elements. However, in order to perceive additive groupings as one, there must be a consistent relationship between the combining elements (Ching, 2007). Below some typical ways to merge elements of additive transformation are listed:

1. Linear
2. Central
3. Radial
4. Grid
5. Cluster

3.1.1 Linear Organization

A sequence of spaces organized along a straight line a line-either or a curved line is a linear organization. It may also be broken into dissimilar sections. Linear space or corridor can be linked by a long or they can be linked directly with each other. The significant of a space in the linear organization can be realized through a different form or a strategic site. A linear organization can limited at dominant space, a different space organization shape, a magnificent design entrance or combined with site topography (Chen, 2011)

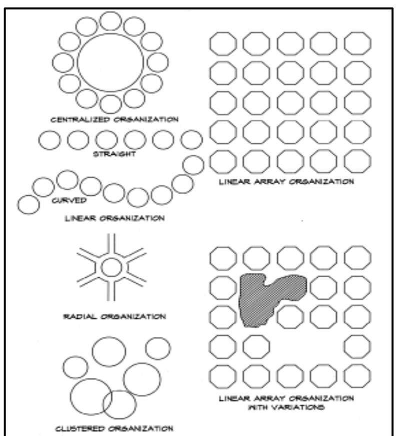


Fig. 1.19 Basic spatial relationships

Figure 38: Simple spatial relationship of linear organization (Chen, 2011)

Usually linear organization involves of repetitive spaces that are all in form, function and size. It can also contain of single linear space that arranges along its length a series of spaces that be different in size, form or function in both cases, each space along the sequence has an exterior exposure (Eckler, 1982).

Although, linear forms contain of forms arranged division in a serious of repetitive space also can be achieved by a proportional change in a form's dimensions, or the preparation of a row of forms along a line. In the final case, the category of forms may be different in nature or they may be repetitive and planned by a separate and dissimilar component such as wall or path (Salvan & Thapa, 2000).

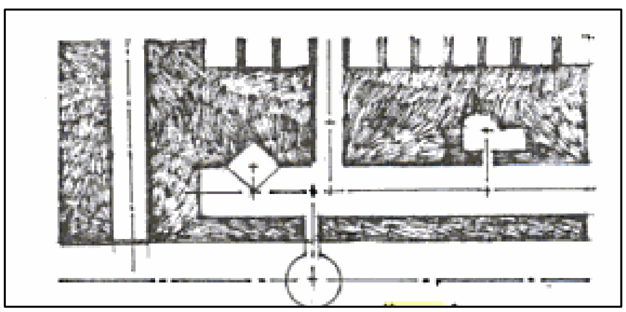


Figure 39: basic organization of linear forms (Salvan & Thapa, 2000)

A proportional alteration in a form's dimensions can be called a linear form. Also, it can be the result of the collection of a sequence of separate forms along a line. In this case, the sequence of forms can be repetitive or different as well, which can be prepared by separate and unique elements such as a wall or path. Moreover, it can be divided or curved to respond to topography, vegetation, views, or other features of a site. In addition, it can classify as an edge of an outside space, or identify as means to enter into the spaces behind it or even be manipulated to enclose a portion of space. Somehow a linear organization is concerned with vertically as a tower component to establish or represent a point in space (Leonardo, 1998).

Never less, the best qualities of traditional linear plans are that they can simply fit into the shape of any site. This means that excavation would be reduced. Since they are linear they can be linearly extended and thus flexible to changes if necessary. This gives the possibility to integrate the plan with the site in a bigger landscape and to design a scheme for a modern way of living.

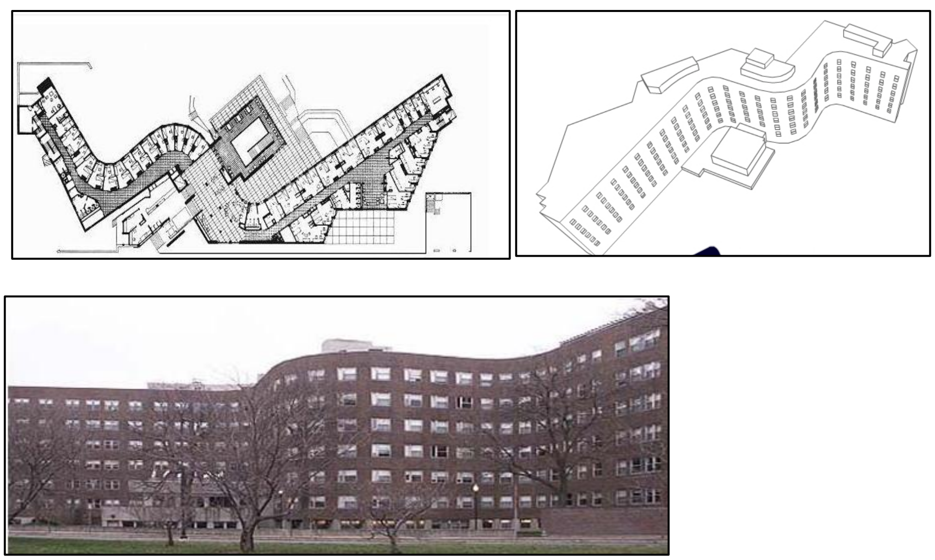


Figure 40: AD Classics: MIT Baker House Dormitory in 1946 by Alvar Aalto (Perez, 2010)

The MIT Baker House Dormitory form well-known a wide diversity of room shapes, designing 43 rooms and 22 dissimilar room forms each floor that although similar. The plan is collected around a single-loaded corridor (Perez, 2010).

3.1.2 Central Organization

Central form can be defined as secondary forms coming together to form a dominant umbilical form. In other words, an intense composition that includes many spaces that are grouped around a huge and main central space (Leonardo, 1998).

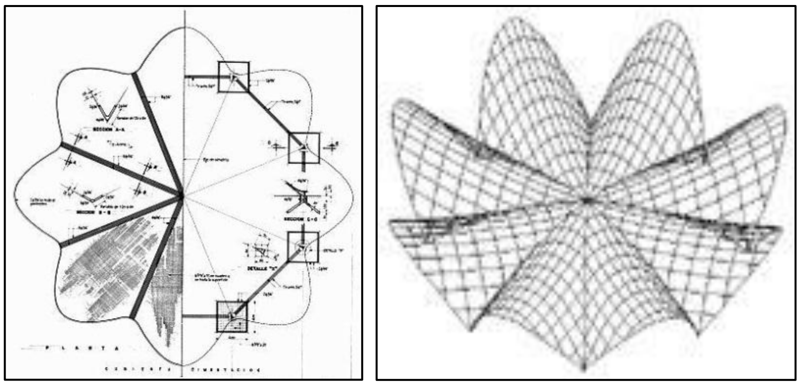


Figure 41: A grid model of Los Manantiales Restaurant central (Leonardo, 1998)

In a centralized organization the model of flow and movement can be either radial, loop, or spiral in form. However, in most cases the pattern may end in or around the main space (Kornberger, 2007). For example, the largest geodesic dome Poliedro de Caracas which is seen in figure 44 has a span 143 meters. The huge part contain under a dome used for trade expositions, concerts, and sporting area with a seating capacity of 13,000 people. Like auto shows, expo marbles. The plan form is central and all the concentration is on the core of the plan, both visual and conceptual (Poliedro architects, 2011).

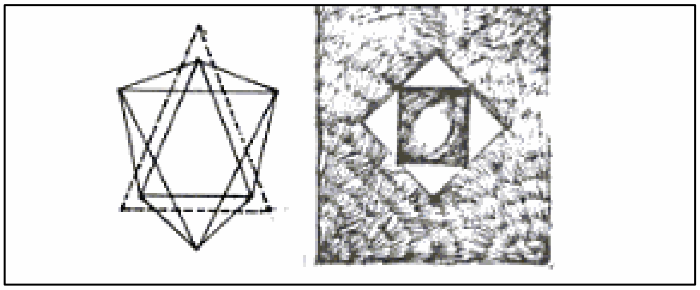


Figure 42: The model of central forms (Salvan & Thapa, 2000)

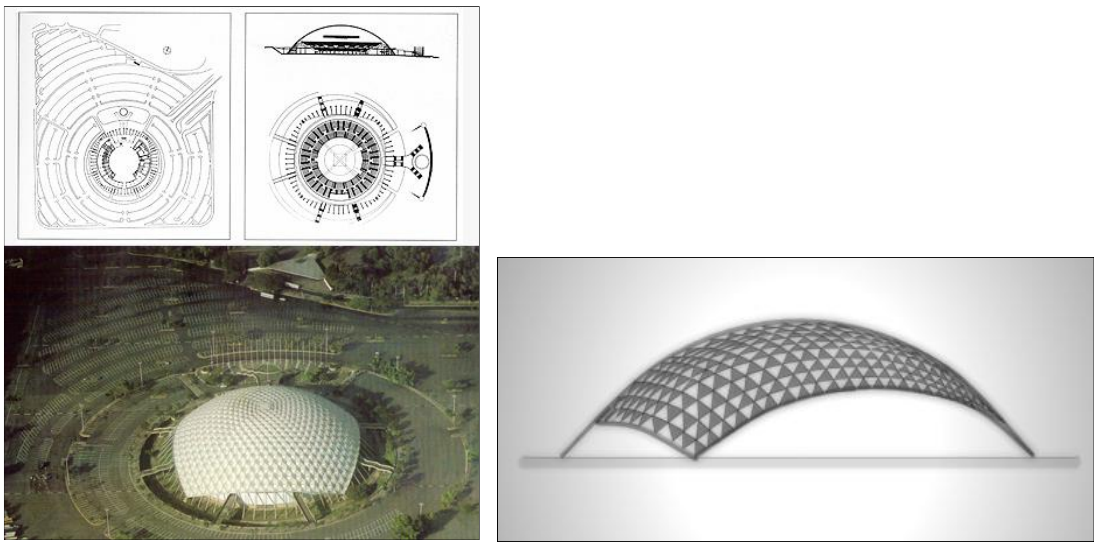


Figure 43: The Poliedro de Caracas (Taffur, 2010)

3.1.3 Radial Organization

When liner forms expand away from the main core element in a radiating way, it can be defined as a radial form, in other words, it units the matters of centrality and linearity into one work of art. It is also important to mention that in such an organization the core can be either the symbolic or the functional center. The central position can be expressed with a visually dominant form and it can also join to become complimentary to the radiating arms. Its central position can be expressed with a visually dominant form, or it can merge with and become compliant to the radiating. Radial forms can expand and merge with some particular features of a site. They can also lengthen their surface to suit specific conditions such as, sun, wind, view, or space. An aerial perspective can be the best way to properly view and appreciate the radial form. This is because the view from ground does not do justice to the central core element and also the radiating outline of its linear arms maybe hidden or unclear from such an angle. The main difference between a centralized organization and a clustered organization is that the former has a geometric foundation for the arrangement of its forms and the later orders its forms based on practical necessities such as, size, shape, or proximity (Ching, 2007).

Fig 44 shows on of the example of radial structure “the Convocation Center diameter is 99.9 meters with the upper of the dome 40.8 meters. Over wood fiber and the central stadium is collected of spring-supported with two cover maple wood system contain the roof is made of aluminum” (Ohio's Convocation Center, 2004).

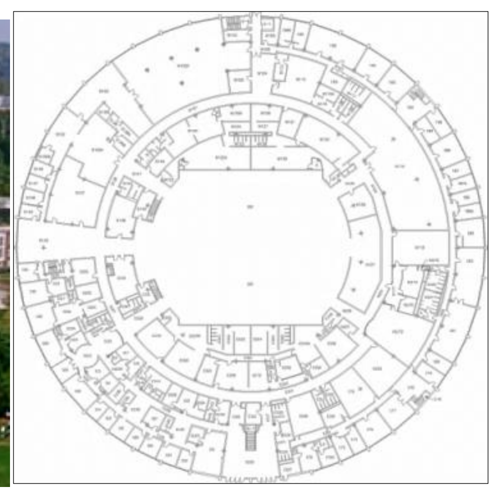


Figure 44: Convocation Center (Ohio's Convocation Center, 2004)

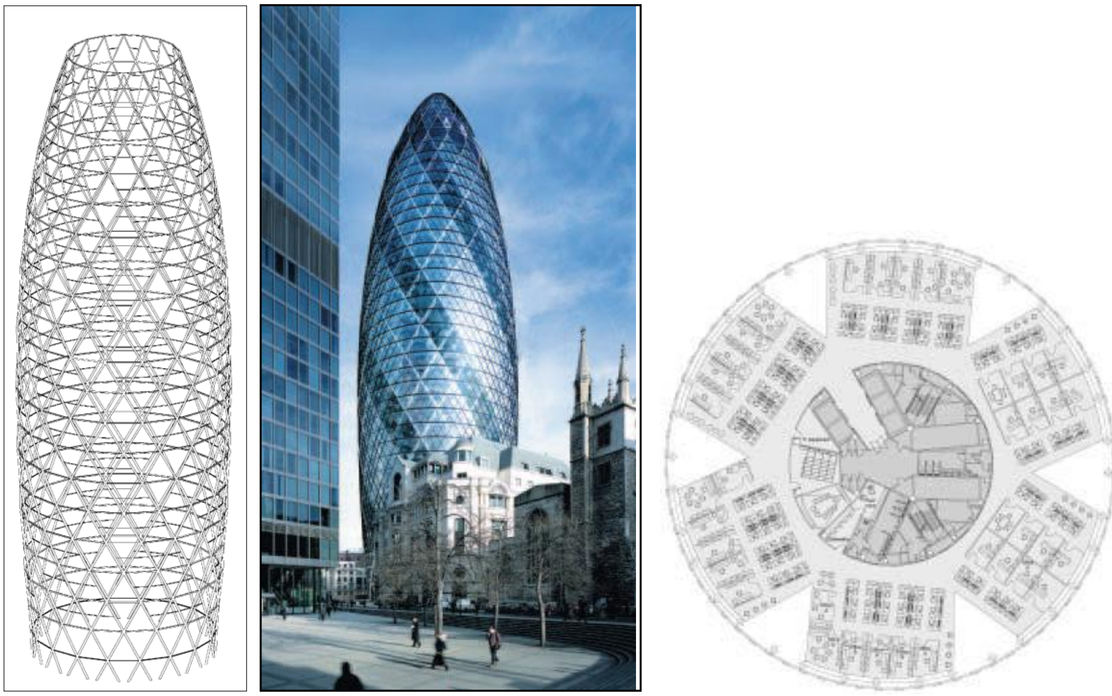


Figure 45: Swiss Re Building (Ma Mistructe, 2006.pp 38)

Another example is the skyscraper Swiss Re Building shows in Fig 33. The concept of that are usages energy-saving methods because of the radial form of the plan. Natural ventilation system works in six shafts between each floor for whole building, the shafts produce a massive double glazing effect; air is inserted between two layers of glazing and insulates the office space inside. (Foster, 2005)

3.1.4 Grid Organization

A grid is an organization of two or more crossing sets of regularly spaced lines that are parallel. It produces a geometric model with repeatedly spaced points at the connections of the grid lines and regularly shaped fields defined by the grid lines themselves. A grid based on a square geometry is the most typical form. Since it has equal dimensions and a mutual balance, it is also nonhierarchical and bid directional. Furthermore, square grids can be utilized in such a way to break the scale of a surface into measurable components to provide an even feeling. Lastly it may be employed to wrap a number of surfaces of a form to merge them, since they are essentially recurring and enveloping geometry (Ching, 2007).

Furthermore, one of the characteristics of a square grid is that in third dimension it produces a network of points and lines. This feature of grids allows any number of forms and spaces to be organized. In such a way grids can be used both for design and also for dimensional organization and effectiveness. It initially proposes to define an architectural grid model as well as a set of operations to construct them (Ching, 2007).Although, plane grids can be divided into four categories, for example, rectangular architectural grids which are recently utilized, triangular architectural grids, polar architectural grids and any other grids that do not fit in the types mentioned above. It is significant to state that by separating the architectural grids in such a way it would necessitate the explanation of a model for each type of architectural grid. However, only the most popular grids are prepared with a model and data-processing instrumentation. The most regular use of this type of modular design is in urban design rather than architectural building plans (Leonardo, 1998).

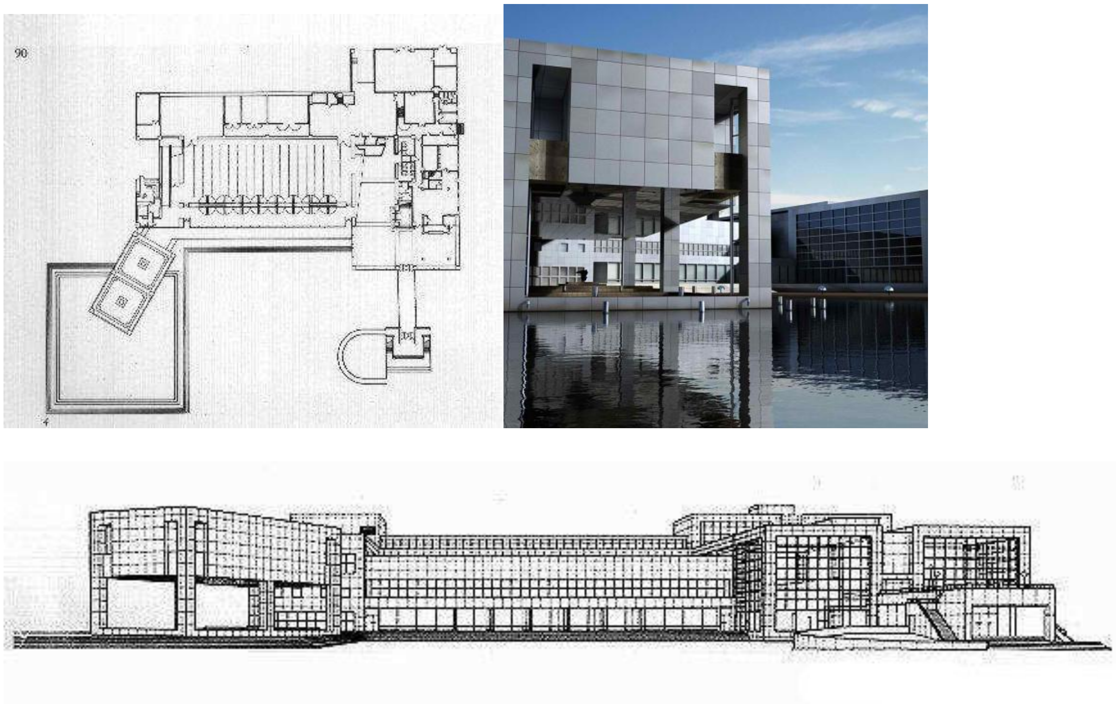


Figure 46: The Gunma Museum of Fine Arts is an Art Muesum designed by Arata Isozak (Gunma Corporation, 2008)

The Gunma Museum of Fine Arts located in Takasaki Japan. The form is grid shape using aluminum cladding as the designing also cuboid geometries form style. The project of the building is constructed on the relations of two architectural systems. First are the skeletal parties of forty-foot cubes as the simple structure, and second are the exhibition places, lighting, administrative offices and stairways (Gunma Corporation, 2008).

3.1.5 Cluster Organization

The general definition of cluster is to extend over so as to cover partly or cover part of the same area like other concepts and techniques in architecture, it can be used in order to help the architect to create more explanation is available at Fig 47 and Fig 48 examples. VitraHaus is a building shown in fig 48, with an unusual appearance includes of archetypal house and the theme of stacked volumes. This five-story building for the first time, was built aim to object for the home. And the main concept was return to the idea of individual house (Vitra Corporation, 2011).

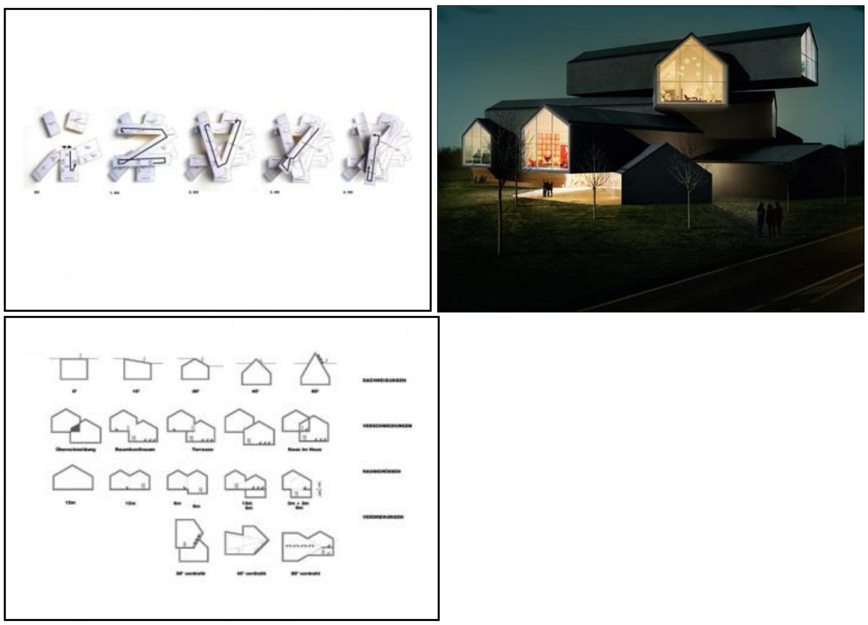


Figure 47: VitraHaus built by Herzog & de MeuronVitra Campus at Weil am Rhein Germany (Etherington, 2010)

As it mentioned before this five-story building design is a little different because of the form of each individual story which show the space by a general characteristic clearly. The structural volume sounds too formed with an extrusion press. This building most important difference with other buildings is the cantilevered up to 14.9 meters in some places that is very hard to even imagine. That makes a 3 dimensional view to whole building (Vitra Corporation, 2011).

Another example is, Mercedes Benz museum architects were Dutch architects UN Studio with the concept of cover leafs in form of 3 circles cluster with a complicated geometrical rotation at the center of these 3 circles. To makes a triangular atrium.

Because of this cluster there was a shortage of space that the architect removes this by adding the height of the building. Here is the design procedure diagram.as it shows the typography is designed in scott Cohen`s studio (Basulto, 2010).

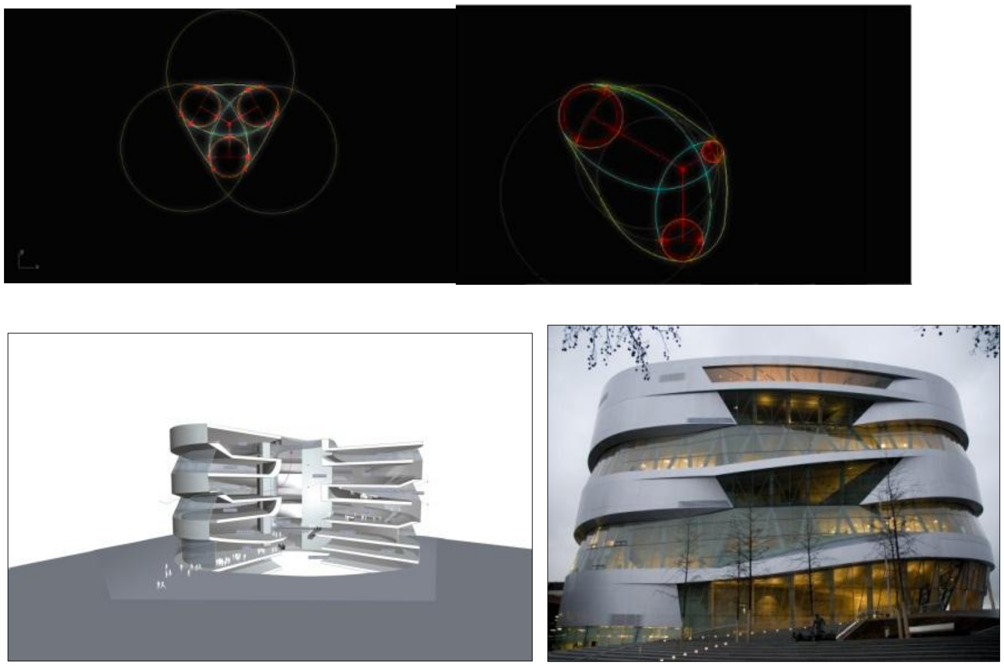


Figure 48: Asymmetric parameterization of the trefoil diagram of Mercedes Benz Museum in Stuttgart (Basulto, 2010).

3.3 Simple Geometry

The three elements of geometry are points, lines, space and planes: A point is an undefined term used to describe for example a location on a map (Ching, 2007).

3.3.1 Triangle

A triangle is one of the basic shapes of geometry, a polygon with three corners or vertices and three sides or edges, which are line segments. Most shapes, however, are drawn with straight lines (Weisstein, 2001).

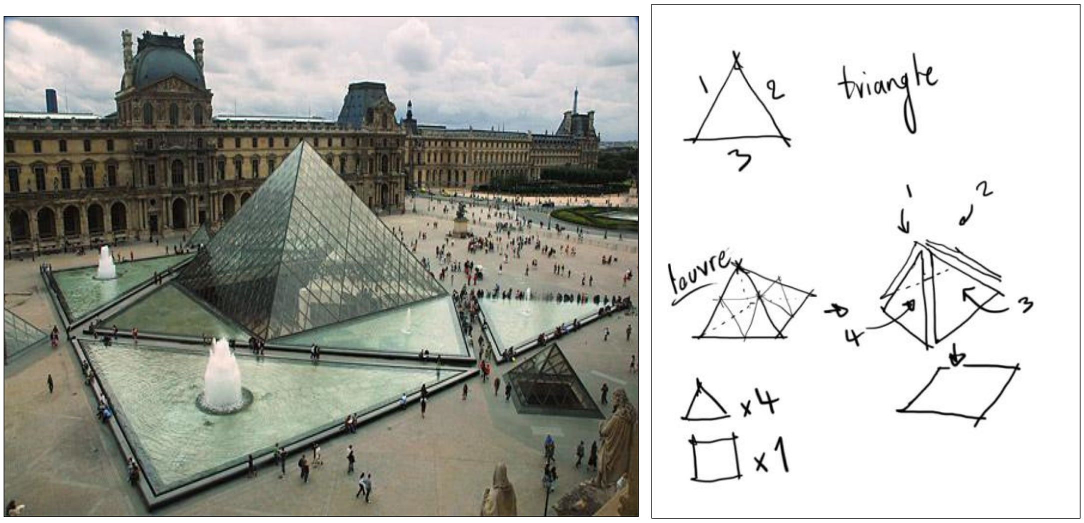


Figure 49: The Louvre Pyramid in Paris design by Francois Mitterrand (Ray, 2010)

For example, The Louvre Pyramid scale shown in Fig 38; the wideness of the glass and steel pyramid is 50 meters on the ground; the huge sculpture soars 36 meters, towering overhead the tourist walkway. Approximately 800 diamonds— or triangle—shaped panes of glass were specially designed to let in the perfect amount of the light and ventilation to the visitor center above (Destination360, 2011).

3.3.2 Square

In geometry, a square is a regular quadrilateral. This means that it has four equal sides and four equal angles (90-degree angles, or right angles). It can also be defined as a rectangle in which two adjacent sides have equal length (Weisstein, 2001).

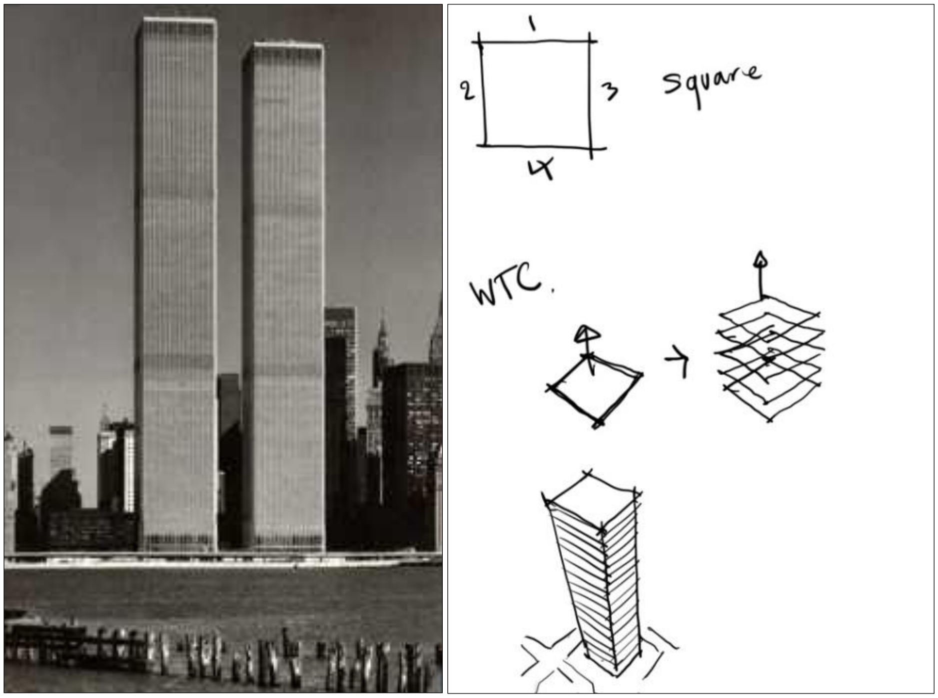


Figure 50: The World Trade Center in New York City by Thomas e. Dewey (D, 2012)

For example, The former of World Trade Center, USA, design concept is rectangular plan about 63 meters dimension of each side with thin office windows (0.45 meters) wide and very heights the material used in cover-ups were enclosed in aluminum-alloy (Silverstein Properties, 2012).

3.3.3 Circle

A circle is a simple shape similar to the Euclidean geometry which includes points in a plane that are middle from a given point, which is the center. The radius of the circle can be defined as the distance among the points and the center (Weisstein, 2001).

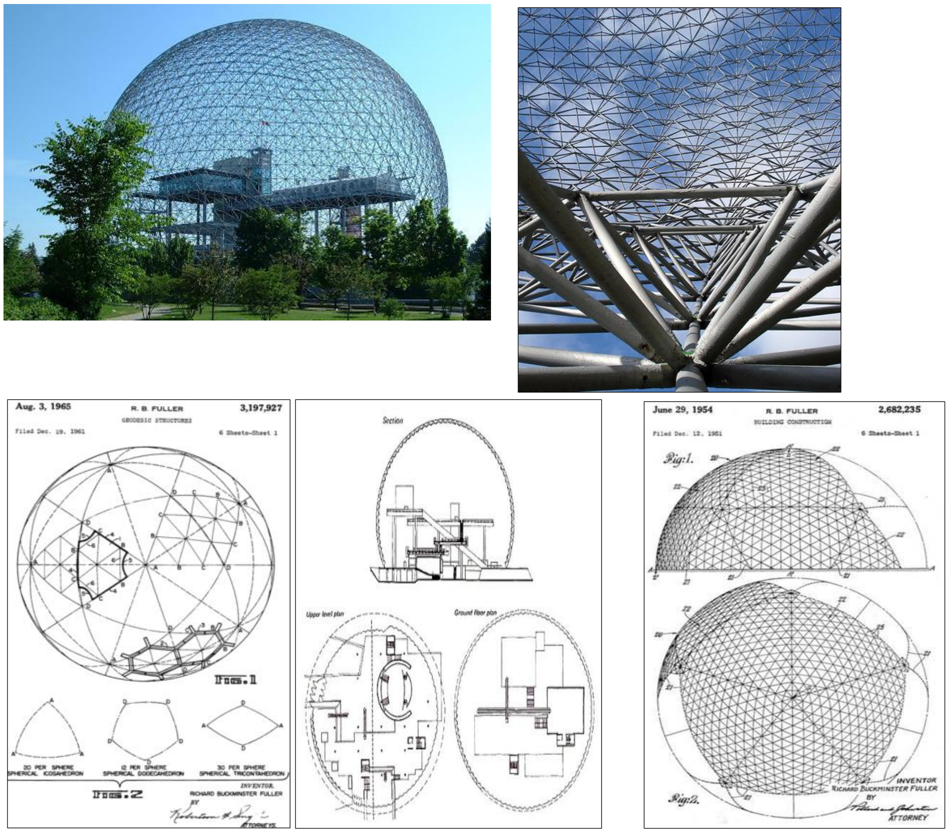


Figure 51: Montreal Biosphere done by Buckminster fuller at Montreal Canada (Sieden, 2000)

Although, a circle is a simple shape similar to the Euclidean geometry which includes points in a plane that are middle from a given point, which is the center. The radius of the circle can be defined as the distance among the points and the center (Weisstein, 2001).

Additionally, forms can be developed by controlling the algorithms of the computer programming. Buckminster Fuller was the first architect to use geodesic domes which they offer both stylistic and structural standard. These domes can be considered as the building blocks for such works (Borgat, Houtman, & Hanselaar, 2003).

The Montreal Biosphere is one of the examples of a circular arrangement and a geodesic dome used an elegant system of coverable shading screens to control the heat inside and a computer adjusted the screens in accordance with the direction of the sun's rays. Besides it’s a proper building in order to show 3 dimensional figures stood 61meters high and had a spherical diameter of 76 meters. It was constructed as a frame of steel pipes enclosing some 1,900 molded acrylic panels (Sieden, 2000). The volume of the sphere can also be used to find the area of the dome. The U.S. was aimed to have an explosion symbol so hired, Richard Buckminster Fuller, to create something really deferent with all before exist (Rohan, 2003).

Another important invention can be considered as, architects derive the forms by working the algorithms of the computer modeling platform. The motivators of this new kind of design were interested in inflatable architecture as well as in the shapes that could be generated from plastic. Buckminster Fuller's work with geodesic domes provided both stylistic and structural precedents. Geodesic domes form the building blocks for works (Borgat, Houtman, & Hanselaar, 2003).

3.4 Form and Geometry Relationship

3.4.1Architectural Geometry as Design Knowledge

The digital design is a new chapter of both artistic and technical design in architecture; also it provides the possibility of new experiences in free-form designs. Helmut Pottmann believes that geometry is potentially effective to generate the new approach of free form design with the needed consideration to structure (Pottmann, 2007).

One of the fundamentals of architectural design has always been the knowledge of geometry, particularly since the language of design in the form of drawings is founded on the rules and laws of geometry. However, not much consideration has been given to this area of research, until the start of the free-form shapes in architecture which has resulted in more consideration for this field. Also, since the geometry of architectural design is becoming more complex and demanding.

Although, the use of digital technology has been dramatically increasing by architects today, this was initially developed by the automotive and aero-plane industries. However, the excessive use of such technologies may result in a number of issues in architectural design. This is because such industries differ in matters such as aesthetics, statics and industrialized technologies (Pottmann, 2007).

Innovations in new tools are one of the main objectives of research in architectural geometry, in order to create digital models. However, it has to meet the standards of shape creation and design phase. Also it has to include the necessary features of the authentic construction such as, materials, manufacturing technologies and structural properties. Another main advantage of architectural geometry is that it facilitates entirely digital workflow, particularly when dealing with very difficult geometries. (Pottmann, 2007).

3.4.2 Form, Shape and Space

Space is a whole definition that forms and shapes are the details, which help the whole meaning get more understandable. In fact the space does not mean without this two factor definition. Form and shape can be categorized in different ways depending on

Their appearance 2 or 3 dimensional, cause in 3 dimensional shapes depth as well as width and height are notable, so forms have two dimensional and shape have three dimensional (Ching, 2007).

Everything in the nature is consisted of shapes or forms. Shape is a two dimensional area that may mean in other ways. A general classification of shapes is geometric and free-form shapes, Geometries are defined by mathematical formulas. The ordinary and regular geometric shapes are circle, square, oval, rectangular, octagon, parallelogram, trapezoid, pentagon, and hexagon. However, free forms or organic shapes are the deformation of these regular forms. They are common in length and width with the geometrical forms but the added factor is depth. For example shapes like square and triangular are geometric; but the free form version of these shapes can be the cubes and cones. Like shapes forms can be both geometric and freeform again. Buildings follow the mathematical rules so they are geometric and human body is a free form. Architects use both forms and shapes with all their classification to represent new forms and shapes (Ching, 2007).

3.4.3 What Different Shapes and Forms Express

A very interesting aspect of shapes and forms in art and in buildings is that it causes us to experience different feelings as we relate them to comparable situations in real life. For instance, curved outlines and surfaces can be smoothing and pointed shapes with sharp projections can create an uncomfortable feeling. If a shape is completely geometric it would look organized and firm and this might signal a lack of sentiment. Moreover, dense materials appear to be physically powerful and strong and perhaps may advocate safety. On the other hand less dense forms may imply comfort. Furthermore, an open or closed shape, form and space may also express emotion. For instance, a sofa is an open form they seems welcoming and invites you to lie down where as a closed form such as a windowless room seem unfriendly and forbidding. In addition, shapes and forms can be either active or static. In this way active shapes are diagonal and perhaps appear more energetic whereas static shapes are often horizontal and may seem clam (Allen, 2003).

Besides all these, form and shape can also be described as either organic or geometric. Organic forms such as these snow-covered boulders typically are irregular in outline, and often asymmetrical. Organic forms are most often thought of as naturally occurring.

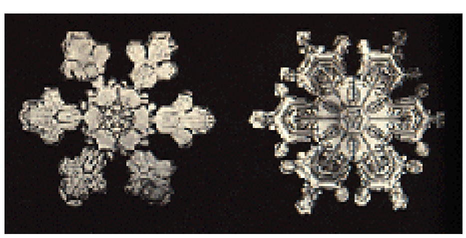


Figure 52: Organic forms example: snow-covered boulders (Pottmann, 2010)

Therefore, regular shapes such as spheres, squares, rectangular, cones, cubes, circles and other regular forms parallel of geometric forms, so architecture regularly composed of those geometric forms to design buildings. (Pottmann, 2010). The structural system of geometrical form of the building depends on material and the way they react to the forces applied to them. This can affect the dimensions, proportion, and planning of the interior spaces within the building volume.

3.4 Geometry

Geometry is a branch of mathematics concerned with questions of shape, size, relative position of figures, and the properties of space. Geometry arose independently in a number of early cultures as a body of practical knowledge concerning lengths, areas, and volumes, with elements of a formal mathematical science (Pottmann, 2010).

Geometry is the starting point of architecture. Even in classic architecture, the mathematical views were the principals (Pottmann, 2010).

Geometry lies at the core of the architectural design process, among these great inventions from the initial form-finding stages to the final construction. Modern geometric computing provides a variety of tools for the efficient design, analysis, and manufacturing of complex shapes. On the one hand this opens up new prospects for architecture. On the other hand, the architectural context also poses new problems to geometry. Around these problems the research area of architectural geometry is emerging. It is situated at the border of applied geometry and architecture. Here are some valuable experiences in high- tech geometric architecture in order to clarify the definition which is mentioned above (Sinan, 1988). As we know the geometry of object is really effective on designing it doesn't matter if it is a perfume package or a great tower. This geometry is able to affect the visional side and eventually the people. In any case the effect of geometry on internal space as deniable, the geometry of the building can indicate or hide or even adjust the light and temperature and totally is effective on internal organization as the geometry tend to get more complicated, the audience gets more pry to catch the concept. In fact it’s a kind of transparency. It seems wonderful to reach. But if the buildings geometry is simple there might be not visual attraction to Get eye catching for audiences and people might be pass it with no attention as a result geometry is one of the most important and also effective factors that an architect or designer must have known.

3.4.1. Pieces of Simple Geometry

When we talk about geometric buildings, the first imagination that would be supposed .It is a very complicated building. But there are lots of simple geometric buildings that have a very simple geometry. Like Convocation Center of Ohio University that just follow of a simple circle form. Simplicity and high spirituality was the main goals of the designer of choosing a piece of simple form like circle.

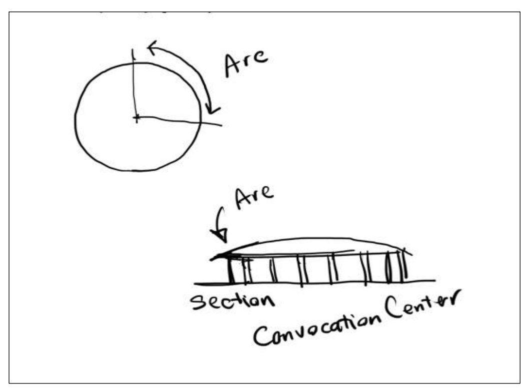
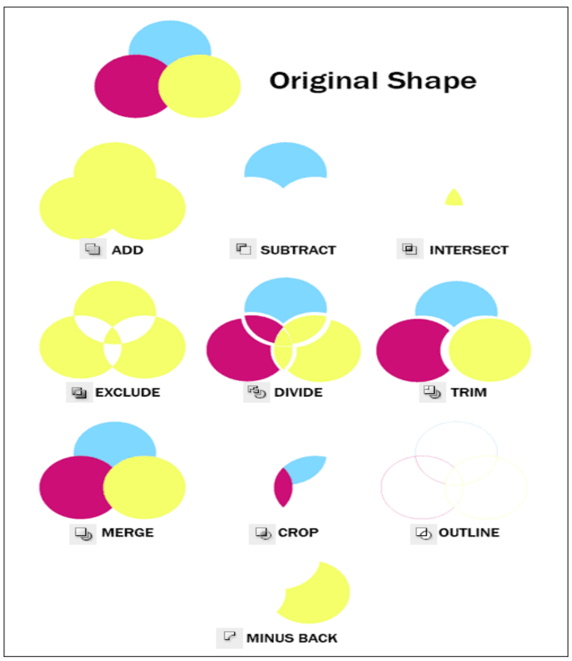


Figure 53: Convocation center Ohio University (Ohio's Convocation Center, 2004)

On the other hand pieces can be joined: As it is mentioned before, there are some basic elements which are pieces in order to make complicated forms. We are going to explain the procedure of what simple pieces in each category are and how to join them in order to create extraordinary spaces. For the first step this is how it looks like using different functions of compound path in case of circles, the final effect after applying the compound path to three colored circles is seen in Fig 42 (Biondi, 2009).



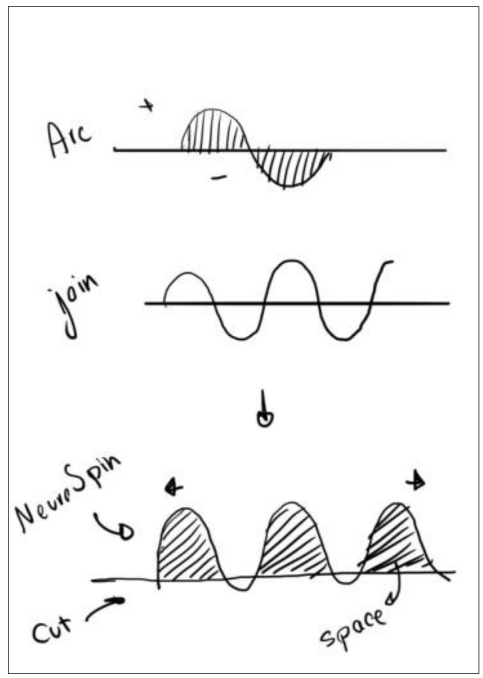


Figure 54: NeuroSpin by Claude Yasconi (Joy, 2010)

The Wave-like roofing shaped like a massive curve, there are clearly separate arches that are capable of housing up to five magnetic resonance imaging machines (Joy, 2010).

3.4.2 Complicated Geometries with Straight Lines

According to the basic introductions about point, line and plane, now it`s time to explain line behavior as a first true tool to design. It`s a categorization of behavior of lines with a common perpendicular in the three types of geometry as it will be explained below:

Positively Curved

A positive curvature corresponds to a repulsive force. Like a sphere which is the only example of positive curvature that does not have any boundaries (Bruno, 1993).

The positively curved shape of Kresge Auditorium; the cylindrically shaped chapel had less window.

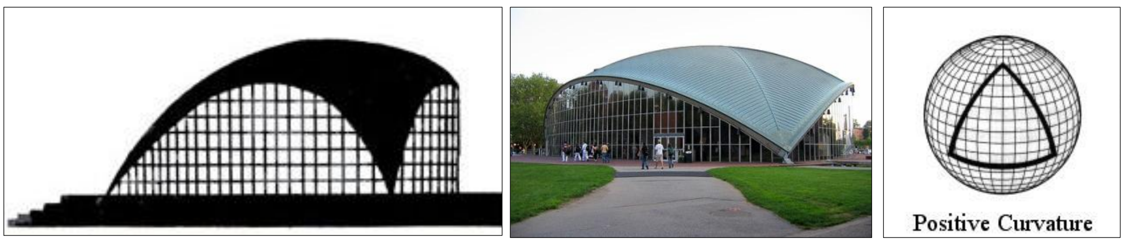


Figure 55: Kresge Auditorium (MIT Archives, 2005)

Negatively Curved

Curved hyperbolically like surface of a trumpet bell or like a saddle , means that Negative curvature. Quite than like the surface of a sphere, this has positive curvature. A negative curvature parallels to an attractive force. Chapel of Nôtre Dame du Haut is one of the example of negatively form which has curved walls and thick shell in the south wall buttress-formed and the huge shell of the concrete roof give the building an enormous, sculptural shape (Glynn, 2011).

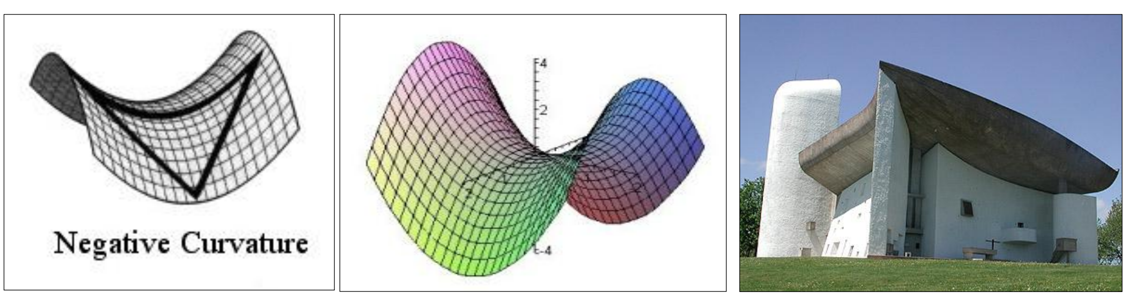
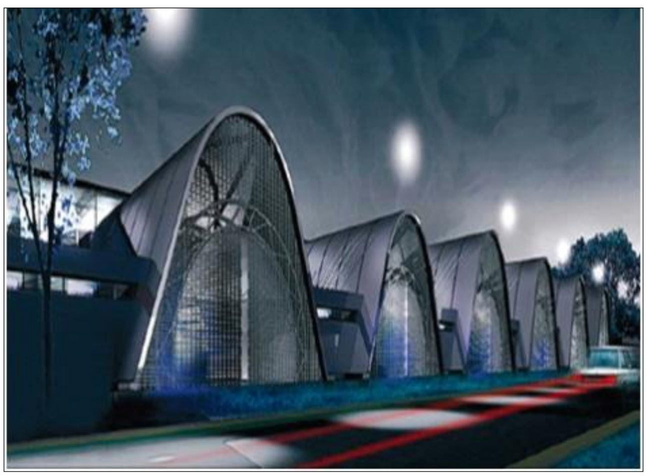


Figure 56: Negative curvature, Chapel of Nôtre Dame du Haut (Glynn, 2011)

Simple mixed is somehow the joint of these two kinds of curvatures can be designed in buildings. It can help mixed the designers to make rhythm and diversification in designing. The order of compose can be different. The Fig 60 shows the example of simple mixed, the construction of roof is wave shaped like giant sine curve a simple mix of positive and negative curvature (Kiser, 2004).



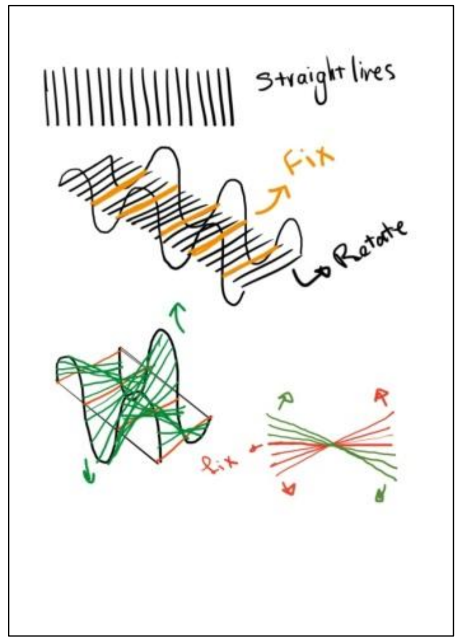


Figure 57: The Neurospin building by Claude Vasconi (Kiser, 2004)

3.4.3 Structure of Hyperbolic Paraboloid

The hyperbolic paraboloid is a doubly curved geometric shape created from the rotation of only straight lines. This shape has the strong effect which was needed in that period of time with the property and possibility of structural necessity. The warping in the shape is the main factor to control buckle in compression also there are some cables to manipulate the tendency to the tension. For example of standard hyperbolic paraboloid As a result the thinness on the long spans which extended a wide area even over 24.384

meters, but with thickness less than 1.5 inches (0.038 meters). It is also a doubly ruled surface like a saddle shape, if we cut this shape horizontally, the cross-section would be a hyperbola. Vertical cross-sections are parabolas. This shape can be complete with straight line but construct a saddle roof from straight beams (Sprague, 2012).

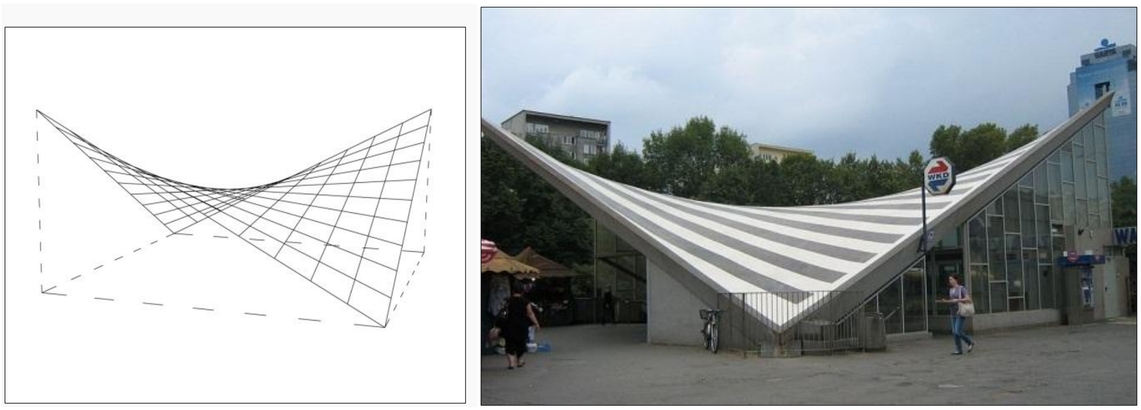


Figure 58: a) Hyperbolic paraboloid structures b) hyperbolic paraboloid structure of Warszawa Ochoa railway station. (Hass, 2005)

3.4.2.1 Cut Pieces of Complicated Geometrics with Curved Line

We explained and showed the curvatures diversification as positive negative and mix of both but there is also some other ways to mix the directions of this curvatures. The best example to explain directional mix of curvatures is Sydney Opera House roofs of the House is covered in a subtle chevron pattern.

3.4.2.2 Joining Pieces of Complicated Geometries with Curved Line

Imagine hyperbolic parabolic as a single form. We can cut the whole form into pieces or curvatures. In fact we can divide the whole form into basic elements of it and finally with joining these curvatures it's possible to create new complicated forms. TWA Terminal roof in new York city has a central curvature on the other definition it’s a cut piece of hyperbolic parabolic form which is located between 2 other curvatures, the join of this pieces inspire the fly feeling to the audience.

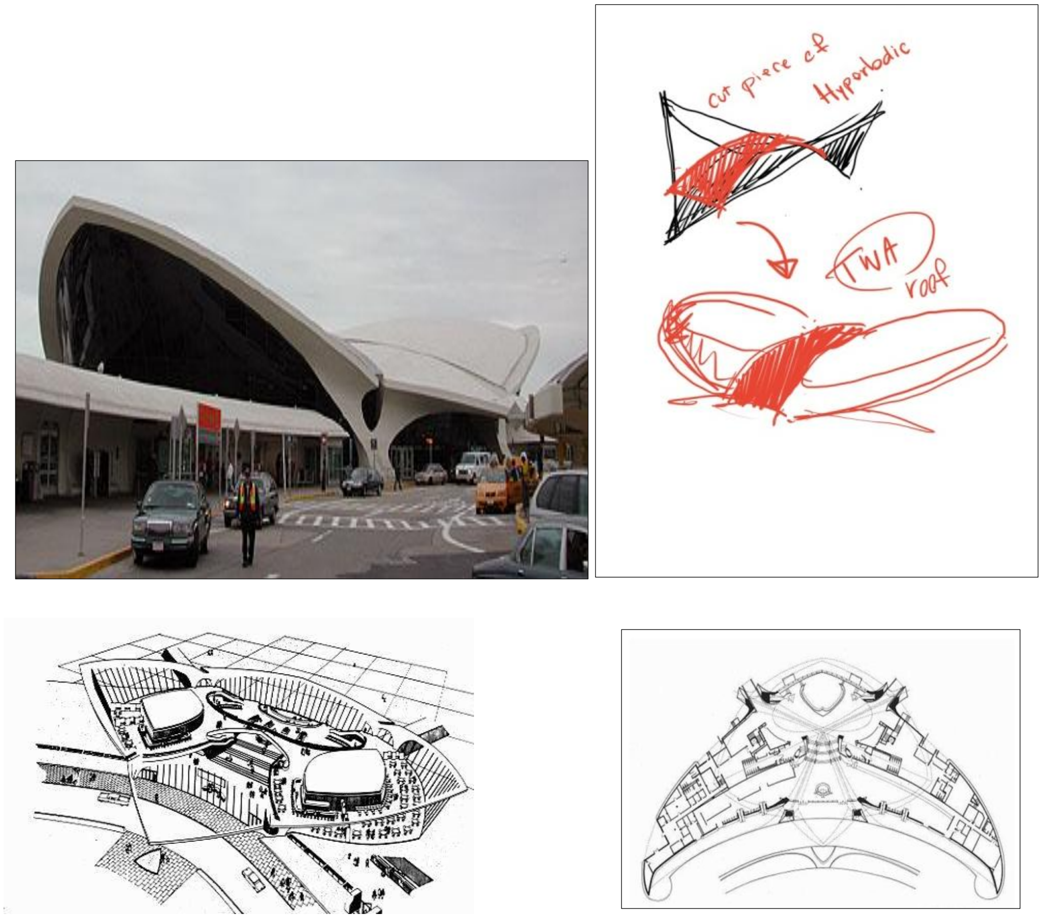


Figure 59: TWA terminal, International Airport (JFK) in New York City by Eero Saarinen (Stoller, 1999)

The Fig 60 shows the Saarinen`s terminal for TWA is known as symbol of flight. The form of the building created attractive, the building is the symbol of a landing eagle. Not just the exterior design but the whole building ambiance is tried to show the romance of flight by live colors and other elements (Stoller, 1999).

The concept was flight and the curved forms were permanent to get the target. The detail of the concept which affects the visual form was 2 huge wings in flight. The interior contain of a sequence ribbon of elements and in this way all the element are continuously run into each other, ceilings to walls and those walls run into floors. These were brief history of modern geometric buildings (Stoller, 1999).

Mixture of all these types: This example can completely show another way of curvature joint. All these joints are flexible enough to match with buildings architectural needs in order to create significant space.

Figure 60: Los Manantiales Restaurant (Burger, 2006)

Candela built on 1958 believes that the natural beauty and tradition in this place is the best concept to propose a compatible and adaptable design for the needed places in this garden. The first idea was a flower lotus floating on the water. This idea helps the designer to get the rhythm and curves which was needed. So the geometric form of lotus idea gives an eight segment volume from the assembly of four hyperbolic paraboloid form (Burger, 2006).

Another example is, The Los Manantiales Restaurant design is octagonal in plan formed by the intersection have four hyperbolic paraboloid structures with a maximum height of 8.25meters and 42 m in diameter that inside is reduced to 5.90 m usual the form kind of lily-like float. Under the vault form are living room and room also restaurant which connects inside and outside of the building, at the center is dancing and ceremonies (Burger, 2006).

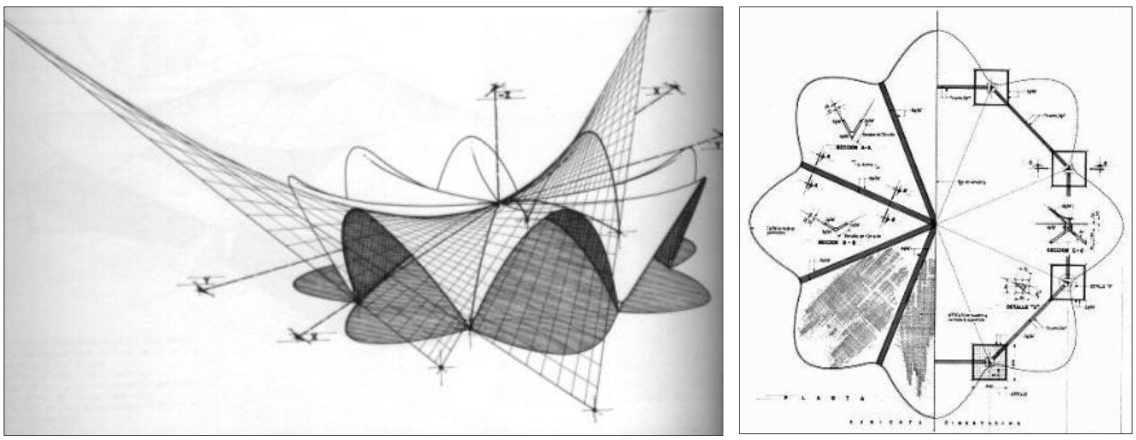


Figure 61: Los Manantiales Restaurant Geometry (Burger, 2006)

3.5 Architectural Free-Form Structures

Blob and Liquid Architecture and Formlessness are the concepts of the late 20th century; Blob architecture is an extremely organic inventing in inflatable buildings; pre-fab plastic structures that show curved dimensions (bulging, cellular, amoeba-like) and soft, rounded. The form created with meatball graphical software produce new and unusual forms in digital design. In the face of its seeming organic, blob architecture is absurd without this and other related computer-aided design programs. CAD is intelligent to produce limitless forms of blob architecture and numerous motivated architects are taking advantage of those apparently unlimited boundaries to thrust architecture to its farthest limits (Organic Architecture, 2011).

Figure 62: Guggenheim Museum Bilbao, by frank Gary, in Spain (The World's Most Significant Corporation, 2011)

3.5.1 Blob Architecture

On the other hand, a new kind of free form architecture known as Blob Architecture, along with more and more developments in shells and spatial structures and wide span enclosures, These forms are irregular and need forms of design, technological and structural systems different from the classical ones. The geometry of Blobs can be defined as free-form, irregular, and not based on Euclidian (planar) surfaces. The designs are based on parameters which are defined by external forces, and they are devoid of formal composition. They undergo their surroundings rather than influencing them. Blob architecture focuses on using ICT (information computer technology) to design, as mass-customization offers alternatives to mass-production.

The solutions for the structural production of functional space systems for Blob buildings are different: Monolithic thin shell, panel systems, pneumatic structures, stretched membrane structures (Borgat, Houtman, & Hanselaar, 2003).

Figure 63: a) The Bubble Pavilion, by Frankfurt 1999. b) The generation of a virtual prototype of the Bubble Pavilion (Biondi, 2009)

Figure 64 and Figure 65 show the generation of a virtual prototype of the Bubble Pavilion. Figure 64 shows the fluid form generation of 3D model powered by 3DStudioMax. Starting from the left, two different drops lay down on the horizontal plane, then they get in contact, they start merging and then the process is frozen (Biondi, 2009).

Figure 65 shows Guggenheim Museum is one of mixed genres buildings that formed in De-construction and blobism. Indeed this building is an exception because there is not any single straight line or flat plane of any size on the structure of the building. The coverage of the structure is polished titanium panels. The reason of this choice was the concept. The concept means to evoke the scales of a fish because the traditional occupation of generations of Bilbao`s natives was fishing .Frank Gehry administers the idea by CATIA computer software (Biondi, 2009).

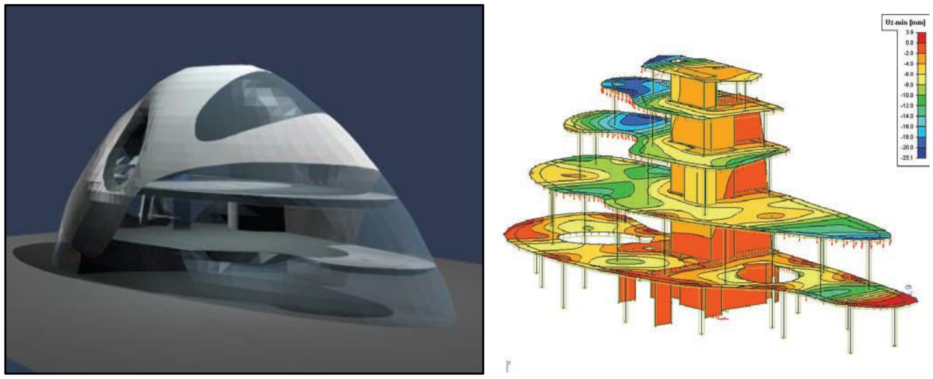


Figure 64: De Admirant Eindhoven blob (Wiltjer, 2009)

The position of the project's site made the structure take on the role as a natural meeting space for the public. In addition to being an iconic building, the 5-storey concrete structure is wrapped in a transparent skin constructed out of glass and steel. Featuring faceted, triangular details, the otherwise smooth and curvy envelope dips in slightly to form light-reflecting dimples which also alter and play with the spatial configuration of the interior. Elliptical cut outs on the floor slabs allow for natural light to reach the level of the square.

Although, the blob is a work of contemporary architecture which is in keeping with the image of Eindhoven as a center for technology, design and culture. (Pronk, 2009)In the center of Eindhoven a high futuristic building is located. The height of this building is 25 m (Pronk, 2009). Two bicycle tunnels and an additional smaller blob is the elements of the centerpiece of a complete re-development. Some shops on the first floor and office spaces on the second floors. According to Arno Pronk, “Eindhoven is unusual in that there is a diverse range of buildings from small apartments to large industrial complexes. A historical city center would have no place for a blob, but in Eindhoven it can enhance the big-city feel. The blob is a work of modern architecture which is in keeping with the image of Eindhoven as a center for technology, design and culture (Pronk, 2009).

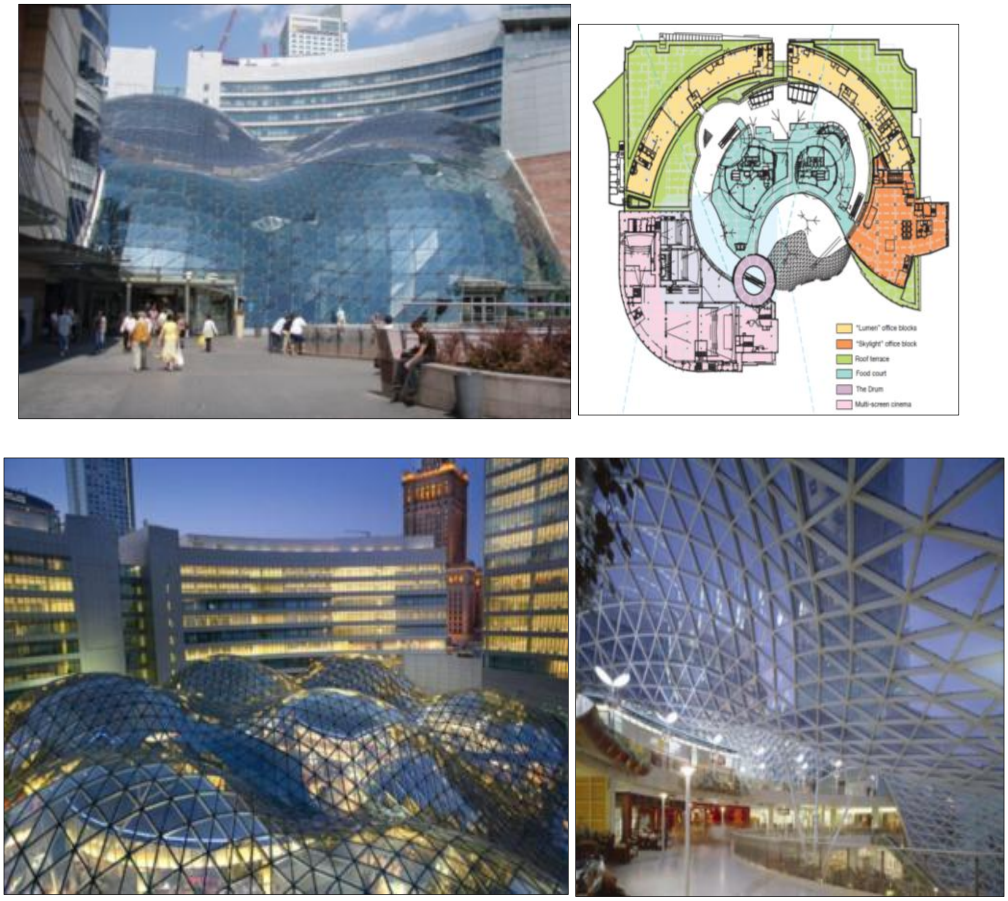


Figure 65: Zlote tarasy (Hennigs, 2011)

Another example is the roof of the ZłoteTarasy building contains of an undulating geometrically complex remaining of welded steel elements supporting triangular glass panels covering the central shopping area and provided the transparent for lighting shading element from central indoor courtyard designed of entertainment complex and commercial, office and concerts. At the front side, the roof comes down to the ground, forming the main entrance to the complex and the primary connector between interior and exterior public spaces. The total area of the building amounts to 205,000 m² cover by 200 shops and restaurant (about 63,500 m²) and a movie theater complex and hotel (Biro, 2011).

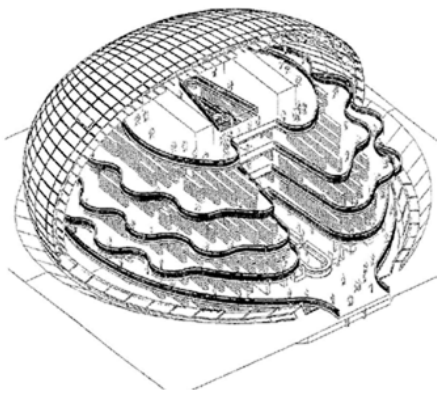


Figure 66: The Philological library building (Klaus, 2004.pp 5)

Among these great inventions, the idea of Philology Library is use of energy conservation and ecology which make active and passive technologies for more energy-efficient. The construction is geodesic dome with concrete structural mass and the materials are glass and steel combining together with curved shining double-layered skin provided transparent space and make daylight and naturally ventilation which means working as sustainable inside of building (Klaus, 2004).

3.5.2Liquid Architecture

The concept of "Liquid architecture" was first introduced by Marcus Novak which is a liquid landscape invented in a digital domain. An interesting aspect of Liquid architecture is that it is not limited by the logics of Euclidean geometries and does not comply with the rational and laws of gravity. He integrates time and space as the main elements. Liquid architecture can interact with the person that lives in it, as it can change accordingly. In liquid architecture, "science and art, the worldly and the spiritual, the contingent and the permanent" converge in a poetics of space, The Water Pavilions by Lars Spuybroek and KasOosterhuis by Ineke Schwartz; can be seen as an example for Liquid architecture (Lootsama, NOX, 2001). Action and movement is the ultimate goal of liquid architectures; with the use of information technology, the idea is to produce patterns that are continuously transforming. This is a new conception that has been encouraged by the developments in cyberspace, meaning information, art, and architecture has been blended and united (Silva, 2005). With the use of cyberspace in liquid architecture designers can create programmable spaces and fluid environments. In other words, the organization of information is in such a way that allows the architect to surpass the laws of physics, such as laws of force and gravity (Silva, 2005).

Figure 67: Water Pavilion, NeeltjeJans, and the Netherlands (Alibaba, 2010)

The Fig 70 shown the Water Pavilion building, the relationships of mankind with nature and technology constitute the central theme of this project. Technology is not simply at the service of man. It colonizes him totally and pursues its own mysterious ends. A school of jumping dolphin’s couples with a squadron of armed helicopters; from their union is born a whole new race of mutants. This architecture is born in a similar fashion (Waters, 2003). This project for a pavilion houses an exhibition on the fresh water cycle. The project is based on the idea of the metamorphosis of water into ice, mist and snow and of architecture into information: the building is not just the envelop for an exhibition but forms an environment in which the different phases of the water cycle become perceptible to the public visitors ‘flow’ along the itinerary, where none of the floors are horizontal. In the glacier ‘tunnel’, words freeze on a metal wall, near the ‘springs’, voices make floor-level water quiver, in the ‘rain-bowl’ clouds are projected in 3-D into an artificial mist. The Water Pavilion is the symbol of liquid architecture; the main reason of this choice is being fully computer base concept building the CATIA (Computer Aided Three-dimensional Interactive Application) (Lootsama, NOX, 2001).

Figure 68: Water Pavilion, the Organic Concept (Alibaba, 2010)

In addition to, the integrity inside and outside of the Water Pavilion is considerable. At the first glance it seems that the walls and ceiling are irrelevant but after paying some attention we will consider that the ceiling extend and in the corners it join to the walls. We can call this building smart because this building is design in the way that the audience or visitors can adjust the elements like light and sound by their mood (Waters, 2003).

However, Liquid architecture is flexible and the concept of the liquid architecture is being dynamic computer-based adaptable to people and environment. As this project was really strange and not conformed to the regular architectural ideas so this negotiation take a lot of time the client were not believe on this perspective which NOX groups illustrated. The hardest part of the project was designing something unpredictable which means that the designer was not allowed to repeat any wall, floor and other building element and also no angel at the building was acceptable (Lootsama, 2001).

As it`s mentioned before; Marcos Novak coined the liquid term when he was going to design a water concept building at the first step it seems strange or even impossible, also being fully computer base was an extra reason to reject the idea. But finally the result get rally notable and admirable (Lootsama, 2001).The building is contained of a positive and wide entrance and in the opposite of this positivity there is a narrow hall which is endless. As it seems there is no border between all the building elements like walls, floors, ceilings and this factor has differentiate Water Pavilion from other buildings. The designers try to direct both architectural design and ambiance design to make a synergy. The ambiance design is consist of electronic sounds the projection direct light, water gleams and etc. The one of the water pavilion attraction is the conformity of inside and outside the building. All features at the façade and volume like the complexity of the material and shape is completely match with the ambiance of the building. The audience feels those complexities during visiting the water pavilion (Lootsama, 2001).Furthermore, Water pavilion as a pioneer architectural building has a very special difference with other buildings. This strong difference is the concept of creating a dynamic system which is compatible with the function. As everyone can understand water pavilion is not just a building as it mentioned before. It has some behaves like a living organism (Rosa, 2003). The delicate point in this project is the interaction between the buildings element and people feeling. This interaction means something like a three-dimensional environment which behaves as a living organism and the audiences are able to interact with this organism. To design and create this new generation building the architects need to be different so they need to use different ways like designing by computer and three dimension software. It doesn't mean that this methodology is limited; on the other hand it may cause more creation and ideas in this project (Rosa, 2003).

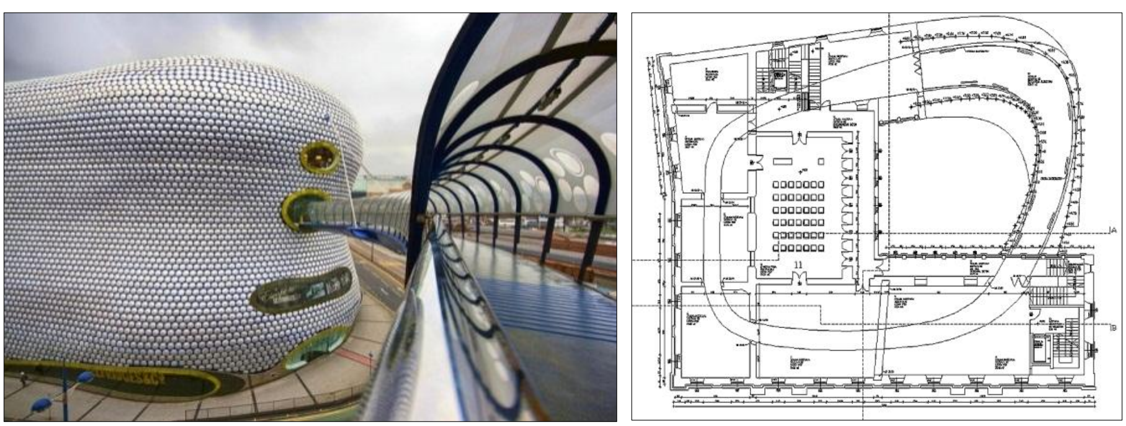


Figure 69: The Selfridges Birmingham building (Alibaba, 2010)

The characteristic of Selfridges Birmingham in Birmingham is designed by Future Systems:

This building is one of the special multistory buildings ever. Because of some specific and unique factors and features which has designed in this case. One of these features is the form of curve, and its material. The material which has been used in the façade system is freeform sprayed-concrete that cause the support of the mentioned curved shape. The next special factor is the retail floor-plates with maximum height and minimum vertical structure. All these features have been took place just because of usage of CAD/CAM technology. These special structures are the goals which may happened by creation of new kind of technology. Generally speaking this solution is holistic one because it can cover both architectural and structural aspects and also the synergy which is earned by this solution is really notable (Underwood, 1998).

"The dominant formal vocabulary of blobs is their generally double-curved surfaces which have special properties from a spatial, structural" (Karanouh, 2005). In certain spatial designing in formlessness, liquid and blob architecture for modeling schematic are using computer program like CAD, Maya, and 3D max. 'From the first consideration the architecture and structural engineers should be considered a bout systematic and designing a conceptual design then designer and builders and producers and co-markers other should be completed in same project(Eekhout,2001).

Furthermore, the certain degree of specific stage from technology that they use and geometrical concept can be expressed. The way of designing of free-form buildings is much more dynamic and not following the rules of the previous generation any more. Classical proportions in building design are completely forgotten. The discussion about good and bad designs will come up, inevitably when the amazement of the visual 'Liquid Design' presentations is brought back to a normal level (Eekhout,2001).

3.5.3 Formlessness

To describe formlessness first of all we need to define form. Form is the shape, visual appearance or configuration of an object. Form means having framed and geometric regulations which is potentiated to translate to mathematics. In architecture when we are talking about ordered form it means that we can fit this form in an ordered frame. For example long time ago when people mind set get used to design all houses in a simple cube which has 6 sides with its plan side, or other basic geometric forms that are definable with numbers and mathematics but designing of those free form buildings from this shape are formlessness and fluid and everyone are able to make a connection with it. It doesn't have any straight lines or corners. We will talk about it in the next part. When people faced with a formless building does not constitute a formal agenda, formlessness doesn't mean openness and structure free, but in the opposite way, the concept of formless architecture is trying to being universal, absolute and non-individual, although eliminate individuality and publish of the community the graphics are obvious.

> “Formlessness has been a vital apprehension of much following architecture, mainly when architectures, turned away from the descriptions of modernity. The construction of the building contributes to its incomplete or unfinished character. Familiar materials are used-timber studs, corrugated sheet metal, and chain-link fence, but they are used in unfamiliar positions, displaced. The positioning of each seems to have resulted from a series of accidents or improvisations, as if the process character of the work unfolded through a number of spontaneous acts that neither anticipated nor recalled the project’s becoming” (Mostafavi, 2002).

In Gehry’s first designs we do not see signs of modern architecture yet, we can view buildings in particular places that have a high quality of light. This manual was the default architectural mindset till deconstruction movement starts and changed forms and volumes and total definition of geometry. And this is the start point of formlessness. Ron Champ Church is the best example of this movement. Little by little human get tired of industrial world and it’s a flash back to the nature and this great source and lots of recent architects are inspired of it. It means those natural concepts are coming in people life, with all its formlessness and disorder. And formlessness means being free, fluid like water when it split over the ground, it doesn’t have any order to pour. It’s just move wherever it grows and change as the soul of the nature (Mostafavi, 2002).

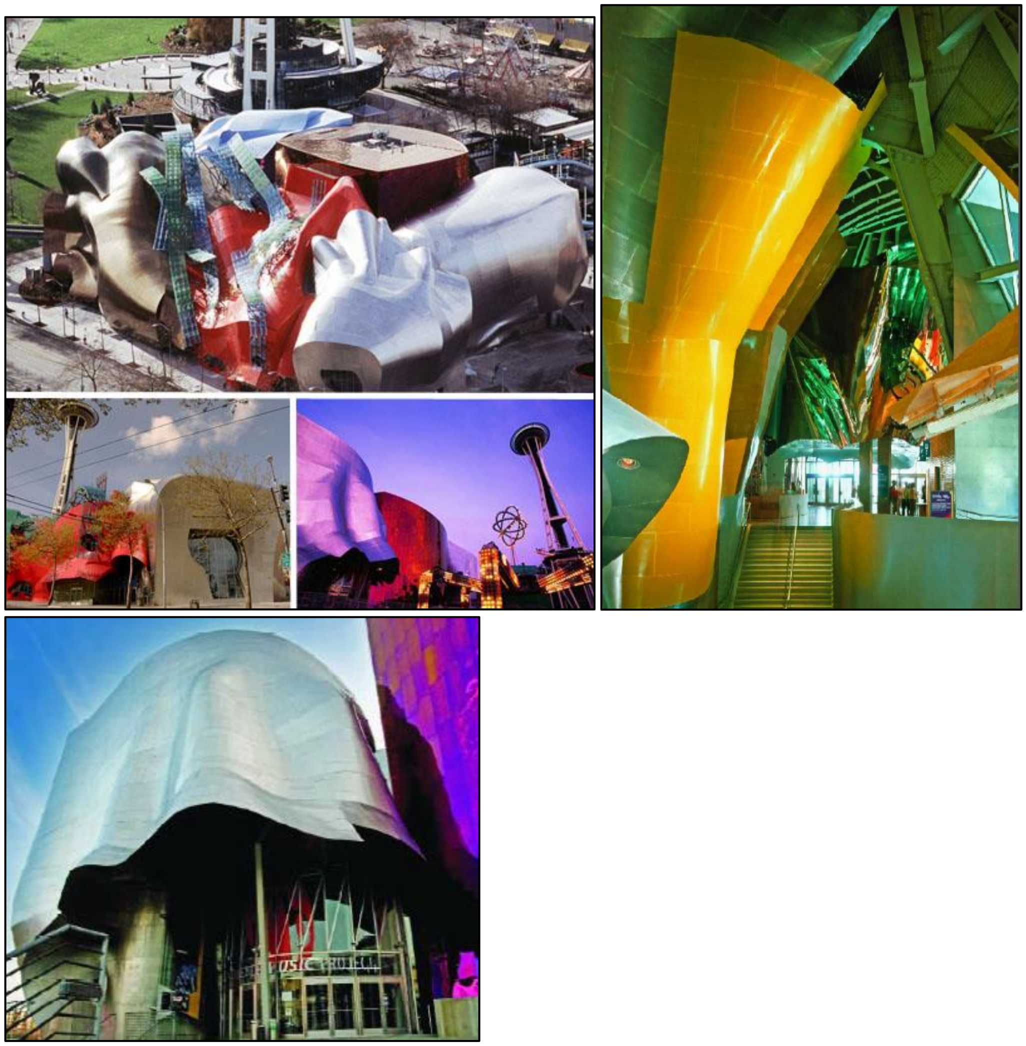


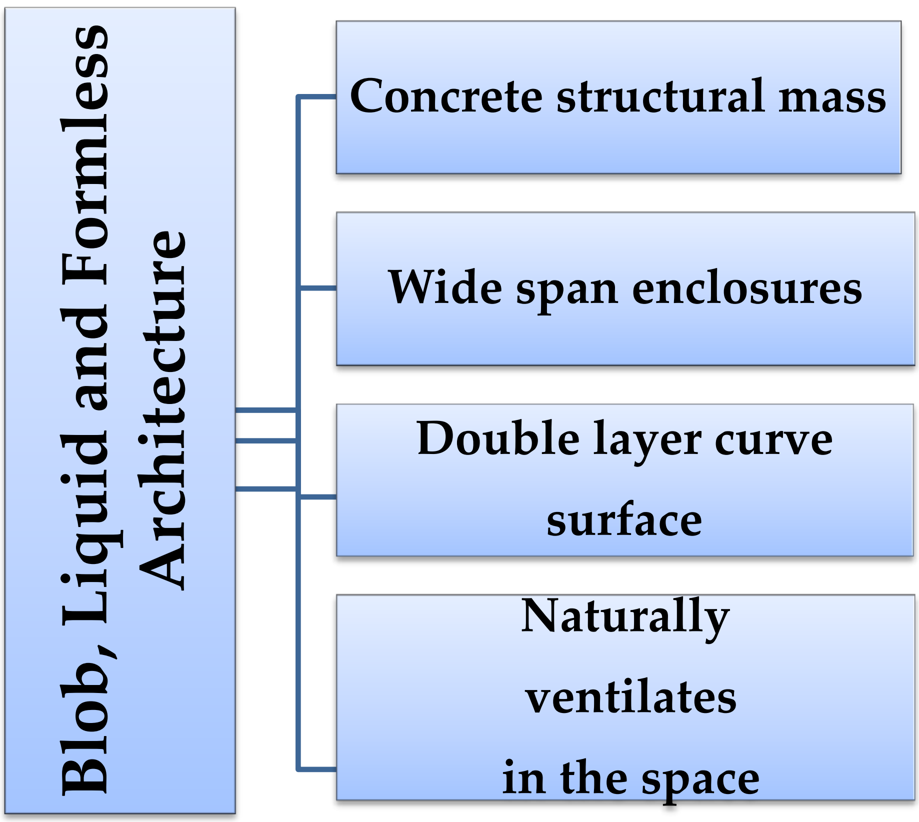
Figure 70: The Experience Music Project in Seattle Washington (Elizah, 2011)

The Experience Music Project in Seattle Washington was designed by Frank Gehry in 1996 contains of a cluster of six globular, bulging units clad in a different of materials and rising up to 25.9 meters in height. The function of inside are big spaces serve variety exhibition area also Each of the units, swelling and undulating sections of the assembly is in a variety color, with the curving and folding shiny surfaces of the highly finished metal skin giving the impress of molded plastic. The outside of tightly fitted fabricated steel frame clad with concrete and sheet metal panels is made from 21,000 aluminum shingles (Johnson, 2007).

3.7 Result of Form and Geometry in Blob, Liquid and Formlessness Architecture

In this chapter we start with basic concepts definition, and their application and transformation in complicated forms. The formal analysis was consisting of form and shape. Geometry definition allows design the forms in a real and possible view. We tried to show the design progress by describing the first elements to the last. So after imaging the total shape and match it with geometry we will have a plan. The plans diversification was the next analysis. And after all we describe the existing space in this plan and volume in a conceptual way like positive and negative space. In any case we have understood all complicated designs were formed by cut pieces and join them in an unusual way. They are also possible by transformations and deformations of all these forms.The whole procedures were moving from form to formlessness. The comparison and analysis between formal and form free examples helps to understand the differences better. The differences is more concentrated in concepts, facades, applications views and any other factors which may change during this procedure. In any case the key factor which should be kept is structure. Although this change procedure may change all factors above, but also the structure can't be denied. A result next chapter is the comparison between all existing structures and finding the more adaptable one with this new generation of formless architectures.

Table 3: The structural system and formal organization concept of blob, liquid and formless architecture



Chapter 4

ANALYSIS OF THE EXAMPLES OF FORMLESSNESS, BLOB, LIQUID ARCHITECTURE

How is it possible to deconstruct old frames and make the formlessness dream came true? Making some comparison between the old methods with the new ones can be very effective in understanding the advantages and disadvantages. And finally remove the weaknesses to promote new methodology. One of the design methods which are really effective on designing the geometry is form finding which is able to facilitate the process of design. Instead of mixing the different geometric systems, form finding can a better solution to design specially for complex forms. In fact the combination of past and ordinary design methods with new needs is an applicable way. As every combination methodologies follow this traditional rule that every complex form consists of details which are the building blocks of that field, so the form finding in complexes is a kind of follow up of traditional version.

In this chapter aimed to choose some important examples between all the case studies to compare. This comparison which takes place by some important factors and features helps us to understand the differences, advantages and disadvantages in cases. Moreover the selections of examples have the extra features between all the case studies.

As you can see in the table 4, we have analyzed 25 case studies. The conclusion of this study can be established based on the comparison of these examples. These buildings have been analyzed based on their structure, formal organization concept their geometry, expression of geometry, form achieved, light/shadow, formality.

About Structure and Material

The structures can regulate to environmental changes which may include modifications to shapes, sizes, boundary conditions and applied forces. For this reason structural system in blob, liquid and formless can be different. According table 4 the structural system in 25 case studies is different, for example The Stadium in Riyadh and The Campus Center has been used same structure which is called membrane structure. the construction are tensile membrane umbrella roof with a vertical central mast and a couple of hanging and steadying cables, which are place below pre-stress by a midpoint ring cable with fire proof material ,in the other hand the type of structure art center Fuji company pavilion, improved the new style, anticlastic form and air-filled structure. The designing was hybrid structure with air-filled portions, held together by cable net system also The Experience Music Project in Seattle has same structure.

About Formal Organization Concept

The formal organization of space can be achieved by forth factor which included radial, linear, cluster and central. It is imperative to consider the physical framework and the external space of a building. According table 4 radial and linear is more useful in to their buildings. For example in comparison to the first 3 buildings at the Table with TWA and Sydney Opera House, those are radial organization concept and the structural are dome but TWA and Sydney Opera House are shell structure and linear. The most of dome structure is radial and most of shell structure and pneumatic is linear.

About Form Achieved

The classifications of geometrical form in digital design include three different types of geometries; The Simple geometries, the complicated geometries and the hyperbolic paraboloid. For example The Experience Music Project in Seattle, Air Forest - Mass Studies and art center Fuji company pavilion are pneumatic structure and complicated geometry compare with Multihalle Mannheim grid shell structure is hyperbolic paraboloid geometry.

About Formality

The formal and formless of spaces is directly related to their geometry and structure. According to the table when the buildings geometry is tending to be organic and disorder the negative space is dominant it means that the interaction between positivity and negativity increase. For example Convocation centers Ohio University and Philological library are dome structure with simple geometry so there is formal geometry but compare to other buildings The Campus Center and the stadium in Riyadh are membrane structure and formless geometry.

About Light and Shadow

Buildings with sport function like Convocation Center in Ohio University and Louisiana dome in New Orleans are common in closed dome roof to avoid lightening inside. On the other hand buildings with function as TWA airport Restaurant Los Manantiales are covered by concrete membrane structure which indicates light inside. The Buckminster Fuller dome, compare with other dome structure buildings like the Louisiana and the Convocation Center indicate the light inside very well at the opposite of other buildings. The Swiss Official Building and the World Tower have similar structure, a whole glass body in order to indicate the light inside which allows the designer to let it enter or hide the light to use the artificial lightening design. In the Bilbao Museum and the Water Pavilion which have membrane organic structure the light control is different, at the Water Pavilion the design tried to avoid light entrance in order to use of artificial light at the opposite side the Guggenheim Museum designer tried to indicate indirect light inside with planning some gaps and tiny voids on the junctions of the structure.

After all these tables clarify that all kinds of structures allow light control but when the goal is light oriented design, the best alternative will be structure and material used, because of its organic and free form potential, as light indication in nature, the light which is passing through transparent skin that dramatically diffuses daylight and naturally ventilates the branches or penetrates in values.

About Geometry

According to the table 4, most of the dome structure buildings are simple in geometry and formed by cube, cylinder, sphere or piece of those Convocation Center and

Louisiana Superdome are designed in the same way. And Sport Palace building in Mexico has the network dome structure that allows the roof to be rhythmic and repetitive the notable point is that there is no major different between internal spaces; they are only different in facades.

Compared with Louisiana and Convocation Center the Restaurant Los Manantiales is more complicated in geometry. The total volume is hyperbola which is repeated in a rhythm. Those TWA Terminal and Sydney Opera House building are inspired by the nature. The first is inspired by wave and the second one by bird's wings and it is a complicated structure which the roof and the body is constructed in concrete shell. The Tall building like Swiss re, have an ordered geometric structure which is extended in height. Water Pavilion is an integrated flowing concept. The formlessness is inspired of water movement, but we found the series of formlessness at Bilbao Museum.

The first experience of using a new technology or applying new forms and concepts is in exhibition structure and little by little transmitted to the other functions like museum and other buildings. The best alternative for implement formlessness is geometrical form concept in structure**,** because it allows keeping and expanding the formlessness and the complicated and formless geometry.

4.1 Result of Analysis of the Examples of Blob, Liquid and Formless Architecture

In order to understand the structure and form behavior, we consider a comprehensive analysis of 25 case studies shown in table 4. Forms, which created in complicated, simple classic and high tech structures with a classification of all case studies information on a table, try to consider important factors and compare the subcategory of all those factors. As the majority of selected cases were digital design building, eventually the rate of every factor indicates the possibility which they cause for the modern forms and finally to get formless architecture. First of all the, organization concept consideration at all cases shows, 24% of all considered cases have radial plan, 40% linear , 24% central and 8% cluster. As the results show, linear and radial organization has the most effect on the creation of the shape and form relationships. The formality rate consideration in all cases shows, 52% are formless and 48% are Formal. So based on these results we can state that formless has the highest percentage of the geometrical form. Consideration at 25 case studies in this research shows, 44% blob, and 20 % Liquid and 20% formless. The Structure and Material consideration of all case studies shows, 32% dome structure, 16% pneumatic structure, 24% grid shell, 20% shell and 8% membrane structure. As the result dome structure is more useful in to three dimensional designs. The consideration of Form achieved of all cases shows, 20% simple geometry, 20% hyperbolic paraboloid geometry and 60% complicated geometry are used. So the complicated geometries, with straight lines or positively curved or negatively curved lines or a mix is maximum percentage of the geometrical form.

Chapter 5

CONCLUSION

In parallel to the technical and theoretical development, blob, liquid and formless architecture, has also noticeably developed as well as form, function, structural, aesthetic properties which constitute one of the significant factors in digital design of buildings.

As this study demonstrates, with the help of 3dimensional software, architects can bring to life all the forms and structures that they envision in their minds despite all the limitations that they faced in the years back. This software provides all the logical process from architecture to construction, particularly in extended and complicated projects. In the case of creating complicated forms, it is desirable to have the similar complexity both in geometry and structure and Computer controlled fabrication methods allow for structures.

The aim of this thesis was to analyze the form and structure relationship in Irregular plans, three-dimensional topography of blob, liquid, formless architecture in accordance with simple, complicated geometries and hyperbolic paraboloid. This study investigated the double curvature surface of all types of structures such as, of grid shell, shell, dome, pneumatic and membrane structure. Moreover, the results revealed the organization of form and their relationship with blob, liquid and formless architecture. As it is mentioned in introduction the aim of the thesis was how to determine the possibility to create formlessness in new organic formless designs with structural considerations.

During this study and after classification and analysis of many cases, it's possible to say that the structures of three dimensional Blob, Liquid and Formless architecture all have wide span enclosure with small thickness and usually the geometrical form is formless. Also, they are all cost effective due to their material and structure. After analyzing all the case studies in this research, the most common structures that are used in blob, liquid and formless architecture were identified. As a result, this study concluded that out of the 11 blob architectures that we analyzed 7 had Dome structure. In the cases related to liquid architecture out of 5 case studies 3 had the shell structure and out of the 5 case examples related to formless architecture 3 used that pneumatic structure. Furthermore, the results show that the simplest form of dome, shell and grid shell all have double layer curve surface and the formal organization is linear although naturally ventilates in space.

REFERENCES

Allen,D. (Mar 2003). *The Surface of Fuller and Sadao` US Pavilion at Montreal Expo 67*. Architectural Design 162, pp. 51-55.

Allen,D. (Sep 2010). *Architectural Geometry*. Architectural Design 206, pp.72-77.

Alejandro,E (2008, Jun 24). *RBD company*. Retrieved April 12, 2012, from tour empezar web site: http://rbd-venezuela-edc.blogspot.com

Alibaba. (2010, Auguest 8). *Daily New Articles Featuring Architecture, Art, Design, Travel, & Technology*. Retrieved september 3, 2012, from Blobitecture: http://weburbanist.com

Al-Nageim, H. (1998). *Steel structures: Practical design studies*. (3nd ed., Vol. 6, pp. 45-58). new york: Taylor ad francis. Retrieved from http://books.google.com.cy/books?id=uukilwuMfZoC&printsec=frontcover&dq

Basulto, D. (2010, august 11). *Mercedes Benz museum / un studio*. Retrieved from http://www.archdaily.com/72802/mercedes-benz-museum-un-studio-photos-by-michael-schnell/

Biondi, E. (2006). *When The Architecture Comes From a Water Drop*. The Blob Structures. Politecnico Di Torino , pp.10-15.

Biro, W. (2011, April 14). *collection of complex architectural free form structures*. Retrieved Jun 20, 2012, from free form structures web site: http://www.freeformstructures.com/2012/04/zote-tarasy-golden

Bradshaw, R. (2002). *Special Structures: Past, Present, and Future*. Journal of Structural Engineering, pp. 691-709.

Brian,D. (2012, May 8). *Everything is big*. Retrieved October 8, 2012, from everywhereonce: http://everywhereonce.com

Burger , N (2006). *An Examination of The Xochimilco Shell.* Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ, USA.

Chajes, A. (1990). *Structural Analysis*. (2nd ed., Vol. 42, pp. 105-173). United Kingdom: Prentice Hall International. Retrieved from http://www.amazon.com/Alexander-Chajes/e/B001HNUS2E

Chel, A. (2009). *Thermal performance and embodied energy analysis of a passive house* – Case study of vault roof mud-house in India. Elsevier;Volume 86, Issue 10, pp.56-60.

Chen, G. (2011). *Landscape architecture: Planting design illustrated*. (3nd ed., Vol. 13, pp. 96-118). United State: ArchiteG Inc. Retrieved from http://www.amazon.com/Landscape-Architecture-Planting-Design-

Ching, F. (1996). *Architecture: Form, space, and order*. (2nd ed., Vol. 9, pp. 39-170). New Jersey: John Wiley & Sons. Retrieved from http://www.scribd.com/doc/38052753/Architecture-Form-Space-and-Order

Colin, P. (2004). *A Friendly Alien*: Ein Kunsthaus fur Graz. Kunsthaus Graz, pp. 34-50. Retrieved May 25, 2012, from Wikipedia web site: http://en.wikipedia.org/wiki/Kunsthaus_Graz

Eckler, J. (1982). *Introduction to Architecture*. (3nd ed., Vol. 10, pp. 199-231). New Jersey: John Wiley & Sons. Retrieved from http://books.google.com.cy/books?id=2Zb1Qxda1uUC&pg=PR4&dq=Introduction to Architecture

El-Bizri, N. (2007). *Geometrisation of Place*. Arabic Sciences and Philosophy: A Historical Journal, 57-80. Retrieved July 14, 2012, from Wikipedia: http://en.wikipedia.org/wiki/Space#References

Elizah, N (2011). *Amazing Architecture.* Retrieved october 12, 2012, from 15 (More!) World's Weirdest Buildings: http://copyplease.blogspot.com

Etherington, R. (2010, February 19). VitraHaus by Herzog & de Meuron, Retrieved from Dezeen magazine digital business: http://www.dezeen.com/2010/02/19/vitrahaus-by-herzog-de-meuron-2

Emmitt, S. (2006). *Multiple Barrel Vault in Shell Structure*. In Barry's Advanced Construction of Buildings (pp. 252-256). oxford: blackwell publishing.

Flc Systems Corporation. (2010, February 17). (F.l. Crane & Sons, Inc) Retrieved April 10, 2012, from http://www.flcsystems.com/?p=3

Foster, N. (2005). *Catalogue Foster and partners*. (2nd ed., Vol. 12, pp. 122-130). United State: Prestel Pub.

Francis, A. J. (1980), *Introducing structures* (Vol. 100). England: program international library, pp. 167-170

Huijben, F . (2011). *Concrete Shell Structures Revisited: Introduing a New 'Low-Tech' Construction Method Using Vacumatics Formwork*. International Conference on Textile Composites and Inflatable Structures (pp. 6-10). Netherlands: ABT Consulting Engineers.

Galant, L. (2009). *Cylindrical thin concrete shells: Structural analysis of the frontónrecoletos roof*. Master's thesis, School of Architecture and the Built Environment

(ABE), Available from Trita-BKN-Examensarbete, ISSN 1103-4297; pp.277. Retrieved from http://www.essays.se/essay

Valley,G. (2010, October 22). *Mega Constructions*.Retrieved March 21, 2012, from http://www.glamvalley.com/mega-constructions

Glynn, S. (2011, Nov 19). *Galinsky Corporation*. Retrieved April 22, 2012, from galinsky web site: http://www.galinsky.com/buildings/ronchamp.

Gunma Corporation. (2008, April 2). *Gunma Museum of Fine Arts* Retrieved from Marvel building: http://www.marvelbuilding.com/gunma-museum-of-fine-arts.html

Hass, J (2005, October 2). *Thomas' Calculus; Dimensions of a paraboloidal*. Pearson Education, Inc., 80-89. Retrieved May 21, 2012, from Wikipedia web site: http://en.wikipedia.org/wiki/Paraboloid

Hennigs, A. (2011, August 21). *Złote Tarasy*, Retrieved from Mapolis Architecture: http://mapolis.com/en/building/Zlote_Tarasy#!wall

J, Schlaich. (1989). *Tensile Membrane Structures*. Invited Lectured in The lass-Congress (pp. 4-10). Madrid: University of Stuttgart and Schlaich Bergermann.

Johnson, J. (2007). *Frank Gehry in Pop-Up*. (2nd ed., pp. 10-24). UK: Baker & Taylor Pub.

Joseph, M. (2012, March 5). *Materials, Surfaces, Structural system*. Retrieved from Space Structure: http://portal.surrey.ac.uk/portal

Joy, E. (2010, 24 Jun). *Architectural Structures*, Retrieved April 25, 2012, from arcades web site: http://archedda.wordpress.com/2010/06/24/architectural-structures

Waters, K. (2003). *Blobitecture: Waveform Architecture and Digital Design.* Rockport Publishers.

Karanoush, A (2005). *Architecture, Againts, & Hyper-Surfaces: High-tech Building Envelope Generation Design*, Informally published mauscrip, Science in Computing & Design, School of Architecture & the visual Arts, East London, England.

Ketchum, M. S. (1997, March 25). *Milo Ketchum's site*. (International Association for Shell and Spatial Structures) Retrieved March 27, 2012, from http://www.ketchum.org/Shell

Kiser, C. (2004, January 5). *Arcspace Corporation*. Retrieved May 29, 2012, from Arcspace web site: http://www.arcspace.com/architects/calatrava

Klaus,W . (2004). "*The Brain*" - The Philological Library, Free University of Berlin. *Liber Quarterly*, pp. 4-8.

Kornberger, M. (2007). *The Architecture of Complexity.* School of Management, Faculty of Business, University of Technology Sydney, P.O. Box 123,.

Kuusisto, T. K. (2007). *Textile in Architecture*. Architectural Design;Builing Construction, 39-55.

Lang, C. (2004, December 1). *NYC-Architecture*. (New York Architecture) Retrieved March 23, 2012, from http://www.nyc-architecture.com/BKN/BKN002.htm

Leonardo, D. (1998) *a Grid Model for Design, Coordination and Dimensional Optimization in Architecture*. France: School of architecture, France.

Lina Bouhaya. (2009). *Mapping two-way continuous elastic grid on an imposed surface: Application to grid shells.* Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium, 990-993.

Lootsama, B. (2001). NOX. *L`architecture d`aujourd`hui 306*, 70,71.

l'Orme, P. (2012, Jun 12). *Treatise on Those Parts of Geometry Needed by Craftsmen.* Retrieved from SBE builders: http://www.sbebuilders.com/tools/geometry

Luca, A. (2011, February 24). *City Wall Paper and Pictures*. (World Press) Retrieved April 10, 2012, from http://www.nationalcapitals.net/sports-palace-mexico-city.html

Ma mistructe, A. (2006). *Swiss Re´s Building, London*. swiss NY, pp. 36-43.

Makovsky, P. (2006, January 16). Metropolismag.com. Retrieved May 25, 2012, from http://www.metropolismag.com/story/20060116

Maria.R. (2010, June 5). *NBM Media Construction Information*. Retrieved October 1, 2012, from www.nbmcw.com: http://www.nbmcw.com.

Martin Kornberger, S. C. (2007). *The Architecture of Complexity*. School of Management, Faculty of Business, University of Technology Sydney, P.O. Box 123.

Makovsky, P. (2006, January 16). *Thought Bubble*. metropolicmag.

Meyer, T. (2005, July 19). *T Boake BES*. Retrieved April 22, 2012, from University of Waterloo: http://www.architecture.uwaterloo.ca

MIT Archives. (2005, July). *MIT libraries corporation*. Retrieved April 8, 2012, from MIT libraries web site: http://libraries.mit.edu

MIT campus Architecture. (2011, July 7). Retrieved April 28, 2012, from central architecture: http://www.centralarchitecture.com

Mostafavi, D. L. (2002). *Surface Architecture.* United State: MIT press.

Nichols, A. (2007). *Applied Architectural Structures*;Structural Analysis and System. Architectural Structure, (pp. 7-10).

Novak, M. (1991). *Liquid Architectures in Cyberspace.* USA: MIT Press Cambridge.

Perez, A. (2010, May 29). *AD Classics*. Retrieved November 1, 2012, from Arch Daily: http://www.archdaily.com/61752/

Pottmann, H. (2007). *Architectural Geometry*. Bentley Institute Press; 1st edition.

Poliedro de Caracas. (2012, July 5). Retrieved April 12, 2012, from Wikipedia.org: http://en.wikipedia.org/wiki/Poliedro_de_Caracas

Pronk, A. (2009). *News and View For International Community*. Retrieved May 4, 2012, from Eindhoven News website: http://www.eindhovennews.nl

Underwood, R (1998). *Structural Design A Practical Guide for Architecture.* New York: John Wiley and Sons, INC.

Raunekk. (2010). *What are the advantage of dome structure*. Retrieved September 14, 2012, from Civil Engineering Group: http://civilengineeringgroup.com/

Ray, N. (2010). *The Web Seen From Above*. Retrieved from Canadatop: http://www.canadatop.com/images/Louvre+pyramid

Whitaker. (1969). *Modern Steel Construction*. American Institute of Steel Construction, IX(2), 3-6.

Rohan, T.(2003). The surface of fuller and sadao. *Architectural Design vol. 73* , 50-56.

Rosa, J. (2003). *Next Generation Architecture: Folds, Blobs, and Boxes.* Rizzoli.

Salvan, G & Thapa, S. (2000). *Architectural and construction data : a digested book for daily use.* Quezon: JMC Press, inc.

Salvadori, M. (1981), *Structural design in architecture*. (2d ed). America: prentice-hall international, pp. 322-345

Say, N. (2006, October 17). *Skyscrapercity*. (vBulletin) Retrieved March 22, 2012, from http://www.skyscrapercity.com/showthread.php?t=571027&page=11

Schueller, W. (1996).*The design of building structure*. (1st ed, Vol. 2,). New Jersey, NJ: prentice-hall, Upper Saddle River, pp. 584-623

Sebestyen, G. (2009, March 21). *Wide-Span Structures*. Retrieved Jun 22, 2012, from Arch-tour: http://arch-tour.blogspot.com

Sieden, L. (2000). *Buckminster Fuller's Universe: His Life and Work*. Basic Books.

Silva, C. (2005). *Liquid Architecture*: Marcos Novak's Territory of Information. The School of Art, pp. 23-30.

Silverstein Properties. (2012). *Silverstein Properties*. Retrieved May 18, 2012, from World Trade Center: http://www.wtc.com/about/wtchistory-wtc-timeline

Sinan,M. (1988, June 3). *Domes From Antiquity To The Present*. proceeding of the IASS-MSU international symposium, pp. 345-548.

Singhal, S. (2011, May 31). The Yas Hotel in Abu Dhabi, UAE by Asymptote Architecture. *Asymptote Architecture*, pp. 5-10.

Sprague, T. (2012). *Hyperbolic Paraboloid and Northwest Modernism*. *arch[be]log*.

Steve,D (2009). *The Green Dump*. Retrieved April 27, 2012, from Blobitecture:11 Cool Ways Archiecture Gets Around: http://www.greendump.net

Stroud Foster, J. (1976). *Structure and Fabric Part 2* (2nd ed., Vol. 5,): Great Britain by the Anchor Press, pp. 301-307

Stoller, E. (1999). *The TWA Terminal: The Building Block Series*. Princeton Architectural Press; 1 edition.

Supartono, F. (2011). *Membrane Structure*. Seminar dan Pameran Haki 2011, (pp. 3-10). Indonesia Melangkah.

Taffur, S. (2010, September 30). *propuestas in_consultas*. Retrieved from Entrevista: W. James(Jimy) Alcock. Premio Nacional de Arquitectura, 1993. Venezuela. Arquitecto venezolano. Karina Lyn. Entre Rayas. Venezuela: http://sancheztaffurarquitecto.wordpress.com

The World's Most Significant Corporation. (2011). *Guggenheim Museum Bilbao*. Retrieved from Architecture; The World's Most Significant Projects: http://archito.blog.com/2011/03/30/guggenheim-museum-

Tian, D. (2011). *Membrane Materials and Membrane Structures in Architecture*. The university of Sheffield, 60-68.

Toussaint, M. (2007). A Design Tool for Timber Gridshells. *Delft University of Technology*, 30-40.

Uithoven, S. (2011). *Modern Architecture and City Planning*. Retrieved April 23, 2012, from http://www.solarflarestudios.com: http://www.solarflarestudios.com

Velimirović, L. (1998). *Analysis of Hyperbolic Paraboloids.* The scientific journal Facta Universitatis, *1*(5), 627 - 636.

Veloso, B. (2010). *Structures Varieties Assignment*. Retrieved April 22, 2012, from pneumatic structural system: http://pneumaticstructuralsystems.wordpress.com

Vitra Corporation. (2011). Retrieved May 22, 2012, from Vitra magazine web site: http://www.vitra.com/en-un/campus

Wales, N. (2006). *Sydney Opera House*. nomination by the Government of Australia of the Sydney Opera House for inscription on the World Heritage List 2006 / prepared by the Australian Government and the New South Wales Government. Australia.

Weisstein, E. (2001). *Equilateral Trian*gle. Wolfram MathWorld. Retrieved May 23, 2012, from wikipedia web site: http://en.wikipedia.org/wiki/Triangle.

Wiltjer, R. (2009). Entrance building “De Admirant” Eindhoven. *CAE housing and buildings*, 3-5.

Wouters, N. (2010). *Pneumatic Structures a revival of formal experiments*. issu, 5-12.

Yellapragada, M. (2010). *Pneumatic Structures The fascination of pneumatic structures begins with the fascination of the sk*y. BA 07 ARC 007, 10-25.

Table 4: Analysis of the examples of Blob, Liquid and Formless architecture

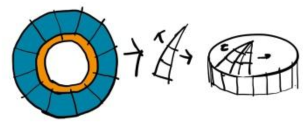
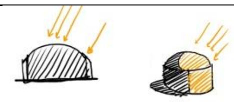
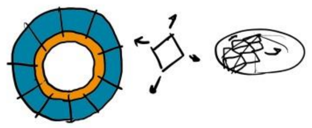
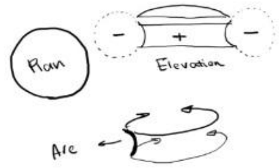
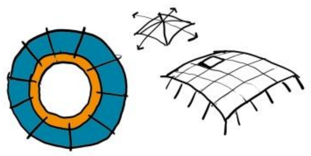
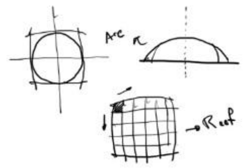
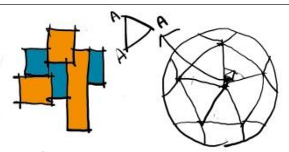
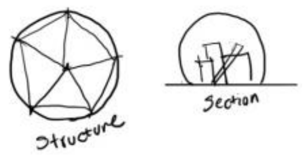
Examples	**graphic expression(Plan And Structure**	**Structure And Material**	**Formal Organization Concept**	**Geometry**	**Expression Of Geometry**	**Form Achieved**	**Light/Shadow**	**Formality**
Convocation center Ohio university	 Blob Architecture	Steel Ribbed Dome	Radial	circle plan, Composite volume (dome and cylinder), geometric		Simple Geometry	 No light penetration-no window on façade-no opening on dome	Formal
Louisiana Superdome	 Blob Architecture	Steel Lamella dome	Radial	circle plan, Central symmetry volume formed by arc rotation around circle center geometric		Simple Geometry	 No light penetration - no window on façade- no opening on dome	Formal
sports palace in Mexico	 Blob Architecture	Steel and Aluminum Network dome	Radial	circle plan, Central symmetry volume formed by repetitive modules on a circle arc geometric		hyperbolic parabolic Geometry	 No light penetration– low heights on the edge cause low shadow	Formal
Buckminster fullerU.S pavilion	 Blob Architecture	Steel Geodesic dome	Cluster	geometric plan, volume formed by organic and disorder repetition inside the membrane geometric		Simple Geometry	 Full light penetration– Transparent membrane cause no membrane shadow	Formal

Table 4: Analysis of the examples of Blob, Liquid and Formless architecture

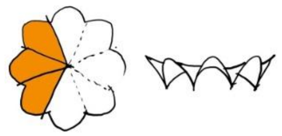
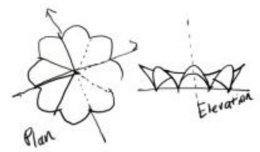
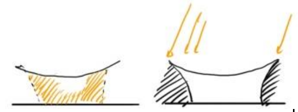
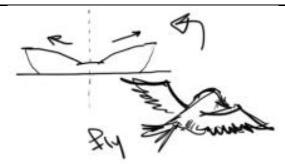
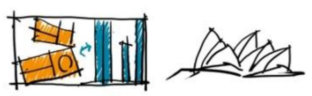
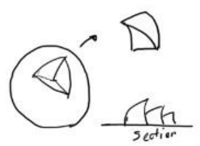
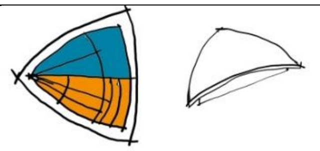
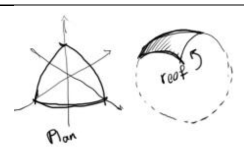
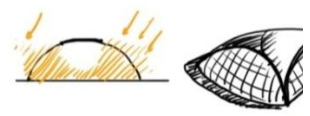
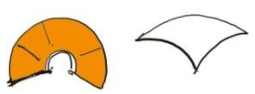
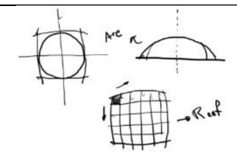
Restaurant Los Manantiales	 Liquid Architecture	Shell Hyperboloid of revolution	Central	geometric plan, volume formed by Central symmetry geometric		Complicated Geometry	 Large openings indicate light inside- Applicable shadows around building	Formal
TWA terminal	 Blob Architecture	Thick shell structure	Linear	organic plan, flying bird wing concept volume formed by symmetry Organic		Complicated Geometry	 Great openings and netted roof indicate light inside	Formal
Sydney opera house	 Liquid and Formless Architecture	Thick shell	Linear	linear plan, volume formed by geometric pieces of sphere geometric		Complicated Geometry	 Rigid membrane prevent light inside- shell pieces shadows on each other and on the ground	Formal
Kresge Auditorium	 Blob Architecture	Shell dome	Radial	rectangular plan, volume roof formed by geometric pieces of sphere geometric		Simple Geometry	 Full light penetration– little outside shadow	Formal
The poliedro de caracas, venezuela(alejandro)	 Blob Architecture	Geodesic dome	Radial	geometric plan, volume formed by repetitive modules on a circle arc geometric		hyperbolic parabolic Geometry	 No light penetration- low heights on the edge cause low shadow	Formal

Table 4: Analysis of the examples of Blob, Liquid and Formless architecture

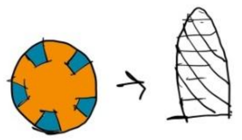
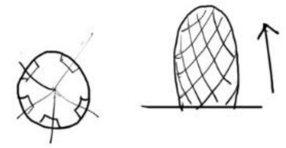
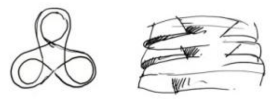
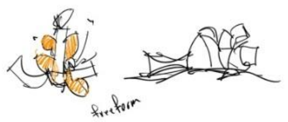
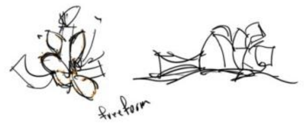
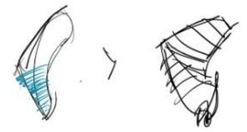
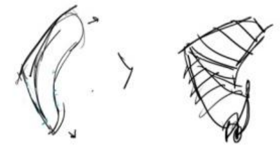
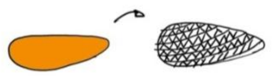
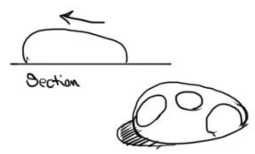
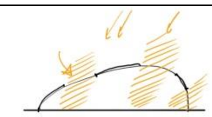
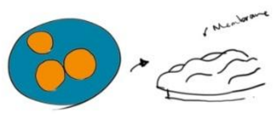
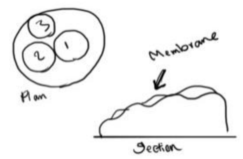
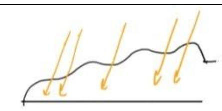
Swiss Re Building	 Blob Architecture	Lamella Dome	Radial	circle geometric plan, volume formed by geometric modular membrane geometric		hyperbolic parabolic Geometry	 4th around Light penetration inside-great building shadow	Formal
Mercedes Benz Museum	 Liquid Architecture	Thin Shell	Cluster	rectangular plan volume formed by organic order of each floor`s rotation geometric		Simple Geometry	 Light penetration through façade and internal atrium	Formal
Guggenheim Museum	 Formless Architecture	Grid shell With Reinforced Concrete Frame	Linear	free form plan, volume formed by free organic disorder Organic		Blob Complicated Geometry	 Light penetration inside through apertures	Formless
Water Pavilion	 Liquid Architecture	Thin Shell	Linear	free form plan volume formed by free organic disorder and random movements Organic		Liquid Complicated Geometry	 Rigid membrane prevent light inside	Formless
Eindhoven blob	 Blob Architecture	Grid shell	Linear	disordered plan final volume is extended organic		Blob Complicated Geometry	 Light penetration inside through membrane	Formless
zlotetarasy	 Formless Architecture	Grid shell	Central	geometric plan formed by circles combination final volume is some spheres joint		Blob Complicated Geometry	 Light penetration inside through membrane	Formless

Table 4: Analysis of the examples of Blob, Liquid and Formless architecture

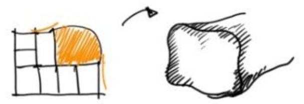
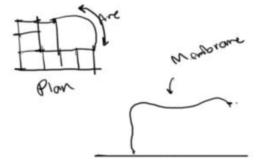
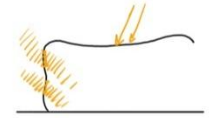
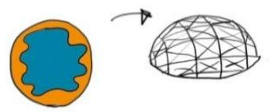
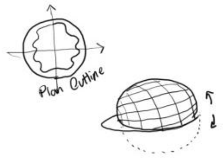
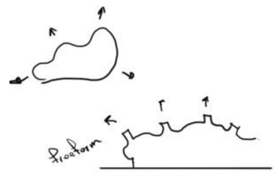
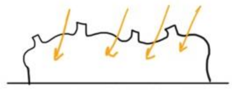
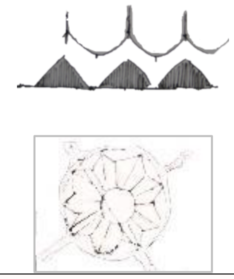
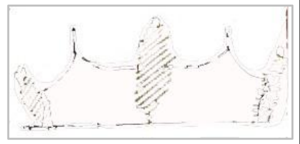
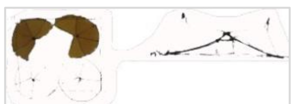
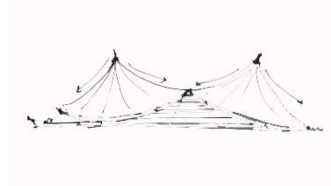
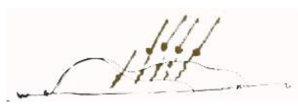
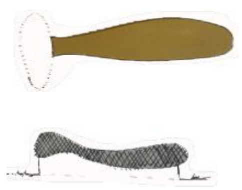
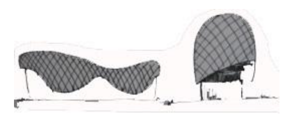
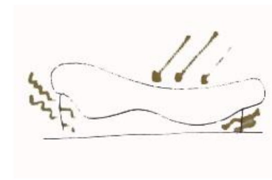
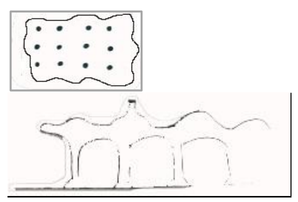
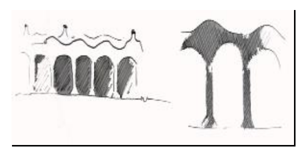
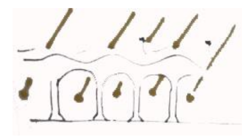
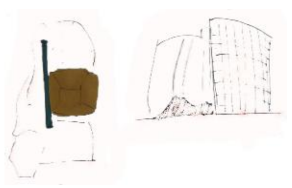
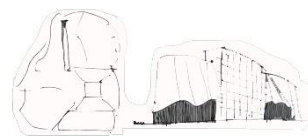
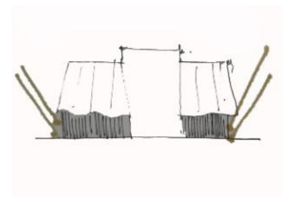
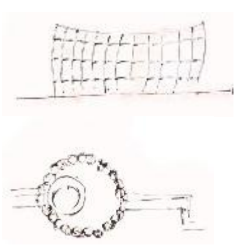
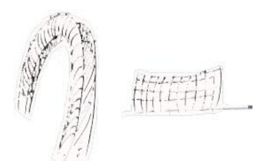
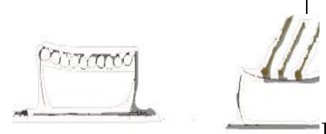
Selfridges Birmingham	 Formless and Liquid Architecture	Grid shell	Central	geometric plan combination of curvature and rectangular final volume is blob and Symmetric plan		Liquid Complicated Geometry	 the membrane prevent light inside except some opening	Formless
Philological library	 Blob Architecture	Geodesic Dome	Central	Symmetric plan Curve form final volume is a sphere piece geometric		Blob hyperbolic parabolic Geometry	 Light is indicate inside and can be controlled by intelligent glasses	Formal
Graz house Of arts	 Formless Architecture	Pneumatic	Linear	disordered organic plan final volume is organic&disorder		Liquid Complicated Geometry	 Light penetration inside through membrane	Formless
The Stadium in Riyadh	 Liquid Architecture	Membrane Structure With fireproof material	Central	Geometric plan, volume formed by Central symmetry geometric organic shape		Complicated Geometry		Formless
The Campus Center	 Liquid Architecture	Membranes structure fireproof material	Radial	Geometrical plan and organic shape		Complicated Geometry		Formless
Multihalle Mannheim	 Formless and Liquid Architecture	Grid shell Timber	Linear	disordered plan final volume is extended organic		hyperbolic parabolic Geometry		Formless

Table 4: Analysis of the examples of Blob, Liquid and Formless architecture

Yas hotel	 Blob and formless architecture	Grid shell Steel frame	Central	Geometric plan, curvilinear shapes,		Complicated Geometry		Formless
Air Forest - Mass Studies	 Formless architecture	Pneumatic	Linear	Geometrical plan and organic shape with symmetrical shape		Complicated Geometry		Formless
The Experience Music Project in Seattle	 Formless architecture	Pneumatic	Linear	free form plan, volume formed by free organic disorder Organic		Blob Complicated Geometry		Formless
art center Fuji company pavilion	Blob architecture 	Pneumatic	Linear	Geometrical plan and organic shape with symmetrical form		Complicated Geometry		Formless